International Text-Book

of

Medical Electro-Physics and Galvanism.

FOR THE USE OF

Medical Students and Practitioners.

BY

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INTRODUCTION.

THE NECESSITY FOR SPECIAL EDUCATION IN ELECTRO-THERAPEUTICS.

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About ten thousand physicians within the borders of the United States make use of electricity as a therapeutical agent daily. Many others find occasional use for it. The surgeon and the ophthalmologist, the dentist and the gynæcologist,—in fact, the specialist in whatever field,—finds it a valuable aid to treatment, an indispensable handmaid. It is the mainstay of the neurologist both in diagnosis and treatment, and the rapid increase of exact knowledge in this branch of medical science is largely due to the service it has rendered. The more familiar we become with the manifestations of electric energy, the more do we recognize its adaptations to the requirements of disordered physiological conditions. It is this lack of familiarity, on the part of the members of the medical profession, with the laws of electro-physics and physiology, more than any other cause, that has retarded the progress of electro-therapeutics. Had every student during the past decade been made acquainted, during his medical course, with the action of electric energy upon the various tissues of the human body, and had he been instructed in the management of such appliances as are commonly employed for controlling such energy, there is not a general practitioner or a specialist among them who would not be making daily use of it in his practice with increased satisfaction to himself and benefit to his patients.

So wide is the range of adaptability of electricity to the treatment of disease that it must become the common property of every physician, no matter whether his work is general or special in its nature, and, such being the case, instruction in electro-therapeutics should have a place in every medical-college curriculum. It is not generally understood what such instruction requires to be of any value to the student.

It is useless for an instructor to attempt the inculcation of therapeutic rules in the use of electricity to a class not familiar with the physical differences between frictional, voltaic, and induced currents; and it is worse than useless for the members of that class to attempt the application of such instruction to the patient if they are unfamiliar with the management of the machinery by which such different forms of electric energy are applied. Such attempts are but doomed to ignominious

failure, discouraging the physician and disgusting the patient, while the abused agent bears the blame until better methods prevail.

To-day the practicing physician needs not to be a pharmacist in order that he may skillfully administer his remedies, for the intermediate work of preparation of medicines for his use is now most ably done, and such knowledge, while it might serve a good purpose in enabling him to detect substitutes and adulterations, would, for most practical purposes, consume time that might be spent to better advantage. With reliable strength and purity, his drug is furnished him in abundance ready at hand; its dosage is simple, its physiological action comparatively uniform; he need but to learn the idiosyncrasies of his patient and his course is clear. But when employing electricity as a remedy a wider range of knowledge is demanded. The operator must know in minutest detail how to generate and control it, to measure and modify it, and be possessed of a manual dexterity in locating its action on the part to be influenced by it. Here is a science and an art to be acquired that needs other methods than the didactic lecture and the text-book. He must not only be well versed in the principles that guide the physicist and skilled mechanic who constructs his electrical apparatus, but he must himself be able to suggest wherein that apparatus may be the better adapted to the special needs of his patients. He must not be dependent upon the enterprising but non-professional commercial agent for information as to what form of electricity to use, and how to use it in certain cases.

The merchant has adopted the rôle of instructor to members of the medical profession, and has many eager auditors. The demand for knowledge is urgent. The schools have not supplied it. The man of money finds it to his interest to respond to it as best he can.

It needs no further illustration or argument to show that the time is ripe for systematic instruction in electro-therapeutics in our medical schools. The profession at work in the field recognizes its needs. The extensive list of disorders yielding to such treatment renders it indispensable. Some medical colleges have for some time recognized its importance and necessity, and have provided for it. Others are falling into line, and soon all will be teaching electro-therapeutics in some manner. But how should it be taught in order that the best results may be attained, and the science most rapidly advanced? What ought the physician to know who undertakes the therapeutical application of electric energy if he would direct his treatment with an intelligent purpose and most efficiently?

First of all, he should be well drilled in the physics of electricity and magnetism. By common consent among educators, such knowledge can be best acquired by laboratory drill, where sight and touch are added to hearing as channels for mental impress, and where the attention is aroused and fixed with greater certainty and success. The student of electro-therapeutics should begin with practical laboratory experience in

the management of continuous-current generators, primary batteries, secondary batteries, dynamos and induction coils, and other apparatus for creating electric energy and for conducting and applying it to the body. It is just as essential for the would-be electro-therapeutist to be brought face to face with, and to learn to overcome, the obstacles that tend to prevent an equable and constant flow of electric energy from a primary battery, as it is for the would-be surgeon to familiarize himself with topographical anatomy in the dissecting-room. Such knowledge is fundamental. There is no time for the one to consult an electrician any more than for the other to refer to a text-book while a treatment or operation is in progress, and an emergency calling for prompt action is as likely to arise with the one as with the other. Physics is not among the requirements for entrance to many of our medical schools, and even those who have had instruction in physics such as is ordinarily given in high-schools and academies do not without a laboratory-training acquire that manual dexterity which is indispensable for managing electric apparatus successfully. Moreover, the laboratory instruction which the electro-therapeutist requires needs to be arranged with special reference to the problems he is to encounter. The resistances with which he has to deal are those of the human body; the electrolysis, that of living tissue; the range of voltage, such as can be borne without harm to vital structure. There are implements and conditions peculiar to the work with which he must become practically acquainted. A laboratory course designed to meet these requirements, and properly educate the medical student to practice electro-therapeutics, naturally divides itself into three divisions, by reason of the character of work pursued in each, and the dependence of each upon that which precedes it. These divisions are: I. Physical; II. Physiological; III. Therapeutical.

I. Physical.—The first or *physical* course should be arranged with a view of presenting to the student all the practical points that are likely to arise in the use of machines for generating static electricity, continuous and interrupted currents, for medical purposes. In order to accomplish this, each student should be required to construct (from the raw material, as far as practicable) his own batteries and other appliances for generating such currents, and for applying them to the body. And where for any reason such appliances are furnished ready-made they should be constructed in the simplest form consistent with efficiency, and their constituent parts left bare for inspection, if possible, so that their action is not obscured and the principle lost sight of through any mystery of mechanism.

The course might begin by testing the strength of currents generated by the action of dilute acids on various dissimilar metals, by which the student will find the position which the various metals occupy in the "contact series," and thus learn to choose those which, for reasons of efficiency and economy, are best adapted for practical use in electro-thera-

peutics. Zinc and carbon being found to meet these conditions, experiments can then be made to illustrate the necessity for amalgamating the zincs, and avoiding polarization in battery action, so as to secure a constant and unvarying current. The form of cell which best meets the conditions of constancy, combined with the highest electro-motive force, may then be determined by tests of a large number of batteries, double and single fluid, and dry. Following these tests the students should, for their further work with continuous currents, be required to construct zinc and carbon bichromate eight- or ten- cell experimental batteries, which should be required to register at least fifteen volts as a test of their accuracy in construction. After determining the electro-motive force and the internal resistance of these experimental batteries, problems for determining strength of currents with unknown resistances should be solved, and then, the current being known from a galvanometer-reading, a series of problems should be given to determine unknown resistances, after which the body-resistances can be tested by introducing some part of the body into the circuit. The student should construct his own electrodes for applying the current to the body. Experiments in divided currents, shunt circuits, and joint resistances should then be undertaken, with a view of illustrating the conditions met with in the action of currents when traversing the various tissues of the body.

The student having thus become practically familiar with the phenomena of electric generation and conduction, and the conditions that attend them, the action of a continuous current in producing electrolysis should then be determined by actual test on a variety of ions, the effects peculiar to the anode and cathode distinguished, and illustrations made of the uses for which such action can be successfully employed in dealing with the diseased condition of the body.

The batteries arranged for generating a current suitable for heating a cautery, and the conditions necessary for successful galvano-cautery work, should be experimentally studied. As a part of this work, each student should be required to make a cautery that will stand the test of a current of eight ampères.

Induction currents should be next considered and the principle of magneto-electric and induction machines inculcated by the construction of temporary magnets, and a study of the phenomena they exhibit in taking on and parting with their magnetism. An induction coil generating primary and secondary induced currents, similar to the ordinary medical induction apparatus, should be put in the hands of each student. It should be so constructed that its mechanism can be readily seen and the courses of the various currents traced. With this apparatus experiments can be conducted upon the body, illustrating the physiological effects of interrupted currents of high electro-motive force on tissue-action.

Frictional electricity should be illustrated by several forms of static

machines, and the student instructed how to operate them for therapeutic applications.

This course of laboratory instruction would consume a period of a longer or shorter time, according to the preparation the students have had in natural science, and as the requirements for entrance to our medical schools advance such practical knowledge of the physics of electricity as is here outlined might with propriety be demanded of the matriculant. No matter where or how acquired, such preparation is indispensable before the student can with any profit undertake the work that pertains to the remaining divisions.

II. Physiological.—Under this head should be arranged a series of laboratory experiments designed to illustrate the manner in which the various living tissues in animals and man respond to the electric stimulus.

No branch of medical science has had more able investigators, or been more fruitful in yielding rich returns, than that of electro-physiology. Such investigations have furnished a firm foundation for electro-therapeutics, and should be made the starting-point for practical instruction. Yet the conditions under which experimental results are obtained in the physiological laboratory differ so materially from those under which the operator in electro-therapeutics is called upon to labor, that a physiological laboratory training is not adequate to supply the needs of education for the electro-therapeutist. In electric experiments in the physiological laboratory, the result has been determined upon a decapitated or narcotized animal with nerve or muscle or viscus brought into immediate contact with the electrodes, while the physician in electric applications deals with the human subject when the cerebral functions of his patient are active and alert, and the skin or other structures intervene between the electrodes and the tissue or organ to be influenced. These changed conditions require methods of investigation peculiar to themselves. A series of demonstrations on the human body intact and in a normal state is the rational prelude to attempts at therapeutical applications.

The student should first be required to obtain the normal nerve and muscle reactions in various parts of the body with both continuous and induced currents, noticing the amount of current required, its density, and the points where the electrodes must be applied to get a prompt response. This range of experiments presupposes thorough anatomical knowledge, and reveals its necessity to the student more convincingly than any verbal argument. These experiments can then be varied by producing overaction in the muscle so as to weary it, and exhibit the retardation in response to stimulus. In an animal the nerve may then be cut, or paralyzed with curare, and the experiments repeated, exhibiting the effects of injury or disease.

The student thus becomes practically familiar with the differences in the polar action of the continuous current in exciting normal reactions in nerve and muscle. The electrolytic action upon living tissue can then

be tested with electrodes of various sizes and material. The effect of density upon the skin from dry electrodes is a most valuable lesson to inculcate, since in unskilled hands the continuous current is capable of doing serious damage to a patient, causing eschars that are extremely slow to heal. The electrolysis of deep-lying structures should be so conducted as to avoid wounds upon the surface from the action of the needles employed. The manner of introducing and insulating them for work of this kind demands experience and skill of a high order. No one will deny that such skill should be attained before the operator attempts it upon a patient, and that superior anatomical knowledge is here also an indispensable requisite for safety in such operations.

Another very common use for the electrolytic action of the galvanic current is the removal of facial blemishes, the technique of which can be very readily acquired in the laboratory.

Cataphoresis, or the introduction of remedies into the tissues through the agency of the anode of a continuous current, affords another field for laboratory demonstration that is destined to prove of great value in therapeutics. The range of remedies that can be thus effectively introduced through the skin and mucous membranes for local or systemic effects are already known to be many, and the laboratory is the proper place for conducting such investigations as will enlarge upon and perfect this method of medication. By employing certain of the lower animals for the purpose, the underlying tissues can be subjected to examination and analysis after such applications, and the result positively determined. Or, if the tests are made upon man, the examination of the urine and other secretions, or the evidences of the known physiological effects of the drug, can be sought for as evidence of the efficiency of the method. It is in this division of the course that the student should be instructed in the generally-approved methods of electric applications, and be made familiar with the physiological effects to be expected from each. Thus, "general faradization," "galvanization of the sympathetic," "local galvanization," or "faradization" of the special-sense organs, and special systems or organs of the body, can be arranged as a series of experiments. The methods and instruments employed to reach internal organs for direct application of currents to them, as the vocal cords, Eustachian tube, the œsophagus, the stomach, the rectum, the bladder, the urethra, the vagina, and uterus, all of which the student should be practiced in before attempting actual therapeutical work, afford a wide field for gathering important information and experience.

The physiological effects of frictional electricity should also form a part of the course of instruction under this head. The cutaneous excitation, the vasomotor change, the increase of circulation, and the so-called "refreshing effects" and the sensations produced by the "electric breeze" can be readily demonstrated, and skill acquired in the management of electrodes for the purpose of producing them.

The student who has been through a practical drill, such as is here outlined, will enter upon the final or therapeutical course with a preparation that will insure him against innumerable blunders, and arm him with a confidence in the agent he is employing that is a guarantee to success.

III. Therapeutics.—The student should now have the opportunity in the hospital wards, the operating-room, and the out-patient department to use the information he has already gained, and learn the value of electricity in counteracting disease.

Here he learns to relieve pain, to promote absorption, to quicken torpid nutritive processes, to excite secretion, to stimulate muscular action, to revive nerve inactivity, to arrest hæmorrhage, to heal ulcerations, to dissipate strictures and tumors, and to cauterize and destroy abnormal growths by means of electricity in one or the other form with which he has become familiar. The therapeutical work goes hand in hand with his study of pathology and diagnosis, and he learns to recognize the diseases most amenable to electric treatment and the method of application best adapted to each. As far as is consistent with the welfare of the patient, the student should be given the entire responsibility in carrying out the treatment when electricity has been found to be an appropriate remedy.

So wide is the range of disorders now found to be helped by electricity that the technique of its management in the clinic has of itself become a matter of so much importance, in many of our hospitals, that a special instructor is appointed to take charge of it. Under his direction the student can be well drilled in all the details of its application in a variety of diseases. The methods employed and the machinery made use of in many of our dispensaries and hospital clinics giving electric treatment are admirable, and the results all that could be desired, but the instruction is oftentimes of little practical value to the student when he begins his own private work, because of his inability to duplicate or maintain the expensive outfit with which he has been accustomed to work, or because any additional information which he may seek to obtain from other sources is couched in language which he does not clearly comprehend by reason of the difference in terms and methods of treatment adopted by those who practice electro-therapeutics. A disparity of results arises also between those who employ electricity in practice, because of a lack of uniformity in the apparatus employed. The rapid advances which all who are personally familiar with the capacities of electricity in one or other form as a curative agent know it to be capable of making are greatly retarded by this lack of uniformity in method and machinery. Electro-therapeutic apparatus can be reduced to much greater simplicity and still retain all the efficiency that it has been shown to possess. Primary- and secondary- current batteries, medical induction coils, milliampère-meters, rheostats, and dynamo-current controllers for medical uses should be made in accordance with standards adopted or approved by the com-

mon consent of those who have proved by their work the value of such patterns. When it is possible to report the treatment by electricity of a well-known pathological state in terms of exact dosage by standard instruments,—all of which is within the range of possibility,—then electro-therapeutics will have reached a stage when its claim to be recognized as an exact science will be far in advance of many other branches of medicine, and the art will keep pace with the progress of the science.

ELECTRO-PHYSICS.

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1. Purpose and Plan of this Section.—There are always two ways in which a scientific instrument can be used,—the blindly mechanical and the intelligent. In the former the employer of the instrument follows certain rules laid down for its use by the inventor, or some one who knows more of its nature and construction. In the latter the employer is constantly verifying and modifying the rules of thumb supplied with the instrument in accordance with what he has learned of its inner mechanism and principle of action; that which Clerk Maxwell, in his childish questionings, called the "go" of the thing.

Now, this first section is intended chiefly for the intelligent medical man who, just as he desires to know the chemical constitution of the drugs he prescribes, desires also to know all that can be acquired without undue labor of that agent—electricity—that has come to be one of his most important tools. Specialists in medical subjects will treat of the different sections under which electrical phenomena have been grouped (voltaic, faradic, franklinic), and will do so from the point of view of their medical applications; and it is considered that a connected view of the whole subject, showing the relations of those great parts and sketching in the intervening districts, will serve the reader as a preliminary view of a strange city from a high eminence serves the intelligent traveler before he descends to plunge into the labyrinth of streets. While an attempt will be made to treat all the fundamental principles of the subject in a simple and easily intelligible way, yet those parts which are most pertinent to medical applications will be treated more fully than less pertinent parts. Especial care will be taken to define and explain technical terms, while less attention will be given to the details of experimental methods and apparatus.

To save frequent digressions in the treatment of electricity itself a concise statement of some parts of general physics is prefixed, and will be referred to, as occasion arises, at different points.

2. Process of Physical Advance.—When attempting at the end of this section to explain what electricity is, what shall we mean by such an explanation? What we mean is, that we shall bring it into line with other more familiar, though perhaps equally unexplained, facts. This is the process of physical explanation,—the reduction of two problems to one. Thus, we shall attempt to show that ordinary mechanical principles and the medium called the ether postulated by light suffice to explain electricity.

3. Matter and Energy the Only Real Things in the Physical Universe.—In discussing what electricity really is, we shall be confronted by the question, What is the test by which we distinguish between things existing in and by themselves and mere relations between things, or between things and us,—that is, ways in which we view things? The former are objectively existent things, the latter merely appearances, and they stand to each other as a landscape to a mirage. Now, the test we adopt is this: A thing does not change in total quantity,—there is no likelihood of the landscape disappearing utterly, whereas the mirage may vanish into nothing; in other words, one is conserved, the other is not. Thus, we take as our test *conservation*, *i.e.*, the property of always remaining the same in quantity.

If, now, with the touch-stone of conservation we try things around us, we shall find that there are but two real things, viz., matter and energy; for each of these is conserved or never varies in quantity. Even force is not a thing, for with a Bramah press or a lever we can, by the exertion of the smallest force, produce the greatest force desirable, and then make it vanish as rapidly. But while matter and energy agree in being conserved, we shall find them differing in a marked way. Each appears in a variety of forms: matter as oxygen, hydrogen, carbon, etc.; energy as mechanical energy, heat, light, sound, and electrical energy. The difference is, that whereas no one form of matter ever (so far as we know) changes to any other form, on the other hand, any one form of energy can change to any other form, its quantity still remaining the same. Hence we say matter is untransformable, while energy is highly transformable. Energy, in fact, only manifests itself in the process of transformation. Its transformability is the life of the physical world, matter its body.

4. Combinations of Different Forms of Matter—Terminology.—At the present time about seventy different forms of matter or *chemical elements* are known, no one of which can, so far as we know, be transformed into any other. But they are capable of uniting two, three, four, etc., at a time, to form compounds differing markedly in properties from the elements. Hydrogen and oxygen are ordinarily gases, but by uniting they form a liquid,—water. This tendency to unite is called *chemical affinity*, and a side-result of electrical advance has been to give a highly probable explanation of this affinity.

Many things indicate that any quantity of one form of matter really consists of very small particles, which, so far as we know, are indivisible, and are hence called *atoms*. All the atoms of any one form of matter are absolutely alike, and chemical compounds are formed by the union of unlike atoms. Hence the smallest part of a compound is really a group of unlike atoms, and this smallest particle is called a *molecule*.

In the union of atoms to form molecules a remarkable diversity shows itself, and will be referred to later. Such unions are not always

monogamous; many are bigamous, trigamous, etc. Oxygen is a highly active bigamist; so that when an oxygen atom unites with monogamous hydrogen atoms to form water it requires two, which is indicated by representing the compound molecule by H_2O. Again, a nitrogen atom takes three monogamous atoms, and so on. This combining capacity of an element is called its valency, and atoms are spoken of as univalent, divalent, trivalent, and tetravalent, or are called monads, dyads, triads, and tetrads.

If, now, we chemically separate such a compound as H_2O into its constituents, the H atoms unite two at a time, to form H molecules, and the O atoms two at a time to form O molecules. But just at the moment of rupture, before this recombination, the atoms are open to accept other partners than ones of their own kind, and hence are at that time in a specially active state as regards readiness to act on foreign bodies. For an obvious reason this is called the *nascent state.*

5. Physical Constitution of Matter—Kinetic Theory.—No very accurate determination of the sizes of molecules is possible yet, but a very rough approximation has been arrived at by Sir Wm. Thomson (now Lord Kelvin) from four different points of view. It turns out that in ordinary liquids and solids there are somewhere between five million and ten billion molecules per inch of length,—that is to say, the centres of two adjacent molecules are separated by something between one-five-millionth and one-ten-billionth of an inch. In a gas the number altogether depends on the density of the gas, and can be reduced to any desired extent by reducing the density of the gas by means of an air-pump. What the actual size of the molecules are, compared with the distance between their centres, we do not know, but certainly it can only be an exceedingly small fraction of that distance.

The progress of research has afforded conclusive evidence that these ultimate particles are not at rest, but are continually in most vigorous motion, however rigid the mass of the substance may be. This motion is of several different kinds:—

(*a*) *Translation of molecules*,—that is, motions by which the molecules move from place to place without any tendency to return. The velocity of this translation may vary widely, and bodies are classified with reference to it into:—

1. *Gases.*—Here the particles continue moving in straight lines until they collide with other particles or with the sides of the containing vessel, when they rebound in new directions. Thus the particles act as quite separate individuals. The velocity of translation in a gas is, on the average, about one-half greater than that of sound in the gas; in the air it would amount, under ordinary conditions, to about 1630 feet per second. This velocity accounts for the great readiness with which two masses of different gases mix when the containing vessels are brought mouth to mouth. The frequency of collision between particles can also be calculated by indirect methods, and also the mean free path, or average distance traveled by a particle between two successive collisions. In the case of hydrogen at atmospheric pressure, the collisions take place at about the rate of 17000 per millionth of a second, and the mean free path is, roughly, four-millionths of an inch. But a gas can be rarefied until the mean free path amounts to several inches.

2. *Liquids.*—Here the particles still have motions of translation, but they are exceed-

ingly small compared with the preceding. Their existence, however, is shown by putting a layer of colorless solution (or water) on a solution of a colored salt (*e.g.*, copper sulphate) and noticing that the two gradually mix by diffusion, as it is called.

3. *Solids.*—Here the velocity of translation is *nil*,—not that the particles are at rest, but they never get far away from their mean positions.

(*b*) *Vibration of Molecules.*—By this we mean a rapid to-and-fro motion in some way or other, such as not to carry a particle far away from its mean position, but to keep it continually moving to and fro around or through it.

(*c*) *Rotation of Molecules.*—By the indirect impact of molecule on molecule, or by some other means, the particles are set into to-and-fro rotations, or it may be continuous rotations.

(*d*) *Oscillation of Atoms in Molecules.*—Finally, the atoms in a molecule are in violent oscillation in a number of ways; and by different means (*e.g.*, heat) these oscillations may be increased in violence until the atoms part company and the molecule is dissociated. The rapidity of these motions can be readily determined from the color of light to which they give rise. It is very great. For instance, an atom of sodium oscillates in three different ways,—at the rates, respectively, of 4.5 hundred million, 6.1 hundred million, and 6.9 hundred million times per millionth of a second.

6. Effects of Motion of Molecules.—One of these, diffusion, has been referred to above. Another is what has been named *osmosis*. When pores exist in a membrane in contact with a fluid, some of the rapidly-moving particles will penetrate and pass through. Now, the molecules of different liquids are moving at different rates, and also are probably of different sizes, and hence will pass through such a membrane at different rates; so that, if such a membrane separate two different liquids, more of one will pass through than of the other. Hence there will be a rise of fluid on one side and a fall on the other. This is called osmosis. For example, if a vessel full of alcohol and closed by bladder be immersed in water, the contents of the vessel will soon increase so much as to burst the bladder. If, on the other hand, the vessel contain water and be immersed in alcohol, the bladder will contract. (For similar effects produced by the electric current see § 60.)

A further effect of the vigorous motion and consequent violent collision of moving particles is that some are ruptured and their constituent atoms separated. They do not, however, long remain separated, but rapidly find partners among similarly dissociated atoms. Above a certain temperature, called the temperature of dissociation, the rapidity of dissociation may exceed that of recombination, and then the fluid is, as a whole, dissociated. The former, or temporary dissociation, at ordinary temperatures, is of great importance in the explanation of electrolysis (§ 61). That such a process is continually going on is evident from the fact that if two salts are dissolved and then mixed, new bodies, being different combinations of the atoms of the two salts, are frequently formed, and, being insoluble in the mixture, are precipitated; and this effect takes place even if the new compound is a less firmly united combination than the original salts.

7. The Form of Matter Called the "Ether."—We know any form of matter merely as an inference from the phenomena of our sense.

Now, a number of phenomena receive their only explanation by the assumption of a very exceptional form of matter called *the ether*. The evidence of its existence is therefore quite of the usual kind. Though its existence can hardly be regarded as doubtful, all the theories of its constitution are still pure speculation. Some of its properties to which we shall refer are :—

(1) It permeates all bodies and pervades all known space, even to the most distant star.

(2) It is affected by the matter of bodies in which it is. It appears to be concentrated in it to an extent depending on the density of the matter. Ether thus bound differs from free ether, in that it transmits short waves more slowly than long ones.

(3) It is continuous, not granular.

(4) Its density is to that of water as is unity to unity followed by twenty naughts (10^{20}), while its rigidity is one-billionth that of steel.

Light consists of transverse vibrations in the ether, and the rate of transverse vibration in a medium is greater the greater its rigidity and the less its density, just as the rate of vibration of a tuning-fork depends on the ratio of its rigidity to the massiveness of its prongs. Now, small as the rigidity of the ether is, it is immensely great compared with its density. Hence the immense rapidity of the vibrations constituting light,—for red light about four hundred millions per second.

Again, if the ether fills all space and is, in some respects at least, like an elastic solid, how are the heavenly bodies not retarded by it? Stokes has given a satisfactory answer, but space will only permit us to give Sir Wm. Thomson's suggested analogy: Shoemakers' wax will offer great resistance to the passage of anything through it, but bullets will pass down through it and corks float up through it, provided sufficient time be given them; the slower their motion, the less the resistance. Similarly, may it not be that the motion of the heavenly bodies is immensely small compared with the resistance of the ether?

8. Energy, Kinetic and Potential.—We now come to the second constituent of the physical universe. By energy we mean the power of doing work. Now, power of doing work resides in bodies in either of two states: (1) in virtue of their motion, *e.g.*, cannon-balls in motion will batter down a wall; (2) in virtue of their shape or position, *e.g.*, a wound-up spring will make a clock go, while a stretched spring or elastic band can, by contracting, pull up a weight. The former kind, or energy of motion, is called kinetic energy; the latter kind, or energy of shape or position, is called potential energy.

Measures of Energy.—The work a moving body can do is found to vary directly as the square of its speed, and also, of course, as its mass, and is taken as $\frac{1}{2}\,\mathrm{m}\,\mathrm{V}^2$. The work a deformed system can do is the force it can exert into the distance through which it can exert it, or Fs. As these are interchangeable, whenever one passes into the other the principle of the conservation of energy requires that

$$\mathrm{Fs} = \tfrac{1}{2}\,\mathrm{m}\,\mathrm{V}^2$$

9. Energy of Vibrations and Waves.—In some kinds of mechanism we have a regular change of the whole energy from the kinetic to the potential form, and back again to the kinetic form, and so on. A simple pendulum gives an example of this. At the highest point of its swing it stops, and just at the moment has no velocity, and hence no kinetic energy. Its energy is all potential,—*i.e.*, it is raised up and could, in virtue of its weight, do work in descending. Again, at its lowest point its potential energy is reduced to a minimum, for it can get no lower, and what it has lost in potential energy has been transformed into kinetic energy. At intermediate points its energy is partly potential and partly kinetic.

The same is true of any kind of vibration or to-and-fro motion, whether to-and-fro motion in a straight line or to-and-fro motion of rotation, such as that of the balance-wheel of a watch.

When a vibration is handed on from part to part of a medium, each part of the medium being set into vibration as the disturbance reaches it, we have what is called a wave,—*e.g.*, an up-and-down motion started at the end of a rope will be transmitted along the rope, giving rise to a succession of waves. Hence, by the above, if we fix our attention on any part of the medium in the course of the waves, its energy will periodically change from all kinetic to all potential and back again; but if we consider a whole wave, at the crest and trough (*i.e.*, the places of greatest *displacement*) the energy will be all potential, but at the mean level the energy will be all kinetic, and at intermediate points the energy will be partly kinetic and partly potential. Considering a whole wave-length at any time, the energy will be half kinetic and half potential.

10. Subdivisions of Energy.—Though all energy we feel convinced is one, as is shown by the interchangeability of its different forms, yet the energy manifested in different classes of phenomena has received different names:—

(1) *Mechanical Energy.*—In such cases as the moving cannon-ball and wound-up or stretched spring, already mentioned, the energy is obviously due to the relative motion or position of the parts, and so may be called mechanical energy. Other kinds of energy are in reality equally mechanical, but not so obviously so, and hence are not so denominated.

(2) *Energy of Waves of Sound.*—Waves may exist in any medium, and such always possess energy. For example, water-waves can do work in the destruction of a breakwater. Sound consists of waves of compression and dilatation in the medium conveying the sound. Its energy is, accordingly, half kinetic and half potential.

(3) *Energy of Heat in Matter.*—A hot body can do work, as, for instance, by boiling water and working a steam-engine. Hence it possesses energy. In what form does this energy exist? We can say at once that it is energy of motion of the particles and of the ether in contact with the particles. The translational part of their motions gives, of course, kinetic energy, and the vibrational part varies between the kinetic and potential forms.

(4) *Energy of Light Waves in the Ether.*—Waves in the all-pervading ether, consisting of vibrations transverse to the direction in which the waves are traveling, are called light and radiant heat, going by the former name when the wave-lengths lie between $\frac{1}{30000}$ inch and $\frac{1}{70000}$ inch, and by the latter name when the wave-length lies outside of those limits. But

we may use the word light in the wider sense, so as to include both of the above divisions. Here, just as in the case of sound, the energy of the waves is half kinetic and half potential.

(5) *Energy of Chemical Affinity.*—Dissimilar atoms unite to form molecules in virtue of an attractive force between them. This force is called chemical affinity. This force of chemical affinity is too slight for consideration until the particles come within a certain range of one another, and then it comes into play and draws them together. Now, when such dissimilar atoms unite, the force is exerted through a certain distance, and hence does work. When work is done, energy is spent and reproduced in a different form; so that two uncombined atoms having a chemical affinity for one another form a system having potential energy. On combination this energy re-appears, either as heat energy, or light energy, or sound energy, or electrical energy. To separate the molecule again into its constituent atoms requires just the amount of energy that they yield up on combination, and when separated they will have just their original amount of potential energy.

(6) *Electrical and Magnetic Energy.*—At the close of this section we shall state the most likely theory as to the nature of these forms of energy.

11. Fundamental and Derived Units of Measurement.—Any property of a body, if estimated numerically, must be so estimated by comparing it with a standard or unit of the same kind. Now, all bodies occupy space and possess mass, and hence we must have units of space and mass. If we have to consider motion or change of any kind the element of time will enter. The units of length, mass, and time are the fundamental units, and may be arbitrarily taken as anything we please. The English have chosen the pound, the foot, and the second, being fixed by arbitrary definition. The French have chosen the centimetre, the gramme, and the second, equally arbitrarily defined. These French units are the most convenient because they are decimally subdivided and multiplied, and hence are the ones usually employed for scientific purposes. They are shortly denoted as the C. G. S. system. For translating from one system to the other the following values may be usefully remembered: A *metre* = 100 centimetres = 39.37 inches; or an inch = 25.4 millimetres = 2.54 centimetres. Again, 1000 grammes make a kilogramme. Half of the latter, called a demi-kilo, is the ordinary commercial retail standard used in France, and is roughly equal to a pound,—more exactly, = 1.1 lb. Hence a gramme = .0022 lb.

Derived Units.—For measuring other properties, units derived from the above are employed. The unit of velocity is a velocity of unit length per unit time, or, in the C. G. S. system, a velocity of a centimetre per second. *Acceleration* is the rate of increase of velocity, and the unit of acceleration is, therefore, defined in terms of the unit of velocity and the unit of time. It is an increase of unit velocity in unit time, or, in the C. G. S. system, an increase every second of a velocity of a centimetre per second. A *force* is whatever produces or changes motion in matter, and hence the *unit of force* is defined in terms of the units of acceleration and mass, as the force which produces unit acceleration in unit of mass. In the C. G. S. system it is called the *dyne.* The dyne, therefore, is a force which every second increases the velocity of a gramme mass by one centimetre per second, or, stated more briefly,

gives a gramme mass an acceleration of one centimetre per second per second. Work is done when a force acts through some distance, and is measured in terms of the force exerted and the distance through which it acts. The C. G. S. unit of work, or the work done by a dyne when exerted through a centimetre, is called the *erg*.

12. Subdivisions of Electricity.—For convenience of treatment electrical phenomena have been divided into three departments: (1) static (or franklinic) electricity, (2) kinetic (or voltaic) electricity, (3) induced (or faradic) electricity. In addition to these there is the subject of magnetism, which will be treated of between (1) and (2).

Static (or Franklinic) Electricity.

13. Definition.—As our ideas are still very dim and vague as to what electricity is, we can at the outset only define the thing we are going to study as that which is made manifest in a certain way and has certain properties. If a dry glass rod be rubbed with silk it is found to have the property of attracting light bodies such as pieces of paper and bits of pith. That which is made manifest by this rubbing, whether it is a thing, or a state, or whatever it is, we call electricity, and the rod is said to be electrified. But if we try a number of different substances to rub the glass with, or a number of different solids instead of glass to be rubbed, we shall find the same thing true. In all cases electricity is manifested. For example, we shall find the property strong when the rubber is of flannel and the stick of sealing-wax.

14. Two Kinds of Electricity.—So far as its action on light bodies —say, a pith ball suspended by a silk string—is concerned, we shall find the electricity shown in all the above cases quite the same. The pith ball is in all cases first attracted by the electrified glass, touches it, and is then repelled by it. The same is true of the electrified sealing-wax. But a difference will soon be discovered. It will be found that after touching the glass the pith ball is repelled by the glass but attracted by the sealing-wax, and after touching the sealing-wax it is repelled by the sealing-wax but attracted by the glass, so that it may be made to vibrate between the two.

Hence we are compelled to recognize two kinds of electricity. These are often called *vitreous* (like that found on glass after rubbing by silk) and *resinous* (like that found on sealing-wax after rubbing by flannel). There are no more than two kinds, for the electrified pith ball is in all cases either attracted or repelled by an electrified body. When we come to discuss what the real nature of electricity is we shall find that there may really be only one kind; that, in fact, electricity is a thing, and that vitreous and resinous only describe different states of that thing. A very old theory associated with the name of Franklin is that the vitreous form is merely an excess of that thing and the resinous a deficiency of it; and so another pair of names have arisen, namely, *positive* instead of

vitreous and *negative* instead of resinous. Though not committing ourselves in any way to this theory, we shall usually employ these terms, positive and negative, for in another respect they are specially happy terms. In algebra positive and negative are opposed terms and mean that two quantities of the same size, one being positive and the other negative, when simply added together amount to zero. We shall find the same true of the two electricities after we have defined what we mean by a quantity of electricity.

15. Hypothesis Provisionally Adopted.—We do not stop here to settle whether all electricity is of one kind or whether there are two kinds. The former theory, stated by Sir William Watson and elaborated by Franklin, is called the "one-fluid" theory. The latter, associated with the name of Sumner, is called the "two-fluid" theory. Its terminology is the most convenient for the description of electrical phenomena, and we shall adopt it as our working hypothesis, though we shall altogether avoid the term fluid and simply speak of two kinds of electricity. To state it at fuller length, it is this:—

(*a*) There are two kinds of electricity.

(*b*) Like kinds repel each other, unlike kinds attract each other.

(*c*) An unelectrified body contains equal quantities of the two kinds, inexhaustibly large, and these two kinds can be separated, to a greater or less extent, by friction or the action of other electrified bodies.

(*d*) The attractions and repulsions mentioned in (*b*) are weaker the greater the distances between the electrified bodies. (More precisely, they decrease in proportion as the square of the distance increases.)

The explanation this theory gives of the pith-ball experiments is the following: When the electrified glass rod is brought near to the pith ball, the positive electricity of the rod separates the combined electricities of the pith ball, attracting the negative and repelling the positive in accordance with (*b*), so that the side of the ball nearer the rod is negatively and the side farther away positively electrified. The negative charge being nearer the rod than the positive one is, by (*d*), more strongly attracted than the positive charge is repelled, and the final result is attraction.

Induction.—This separation of the electricities of an unelectrified body by the action of an electrified one is called induction. On touching the rod the negative electricity of the ball is neutralized by an equal quantity of the positive of the rod, and so the ball is left positively charged. To explain the action of an electrified sealing-wax rod on a single pith ball we have only to interchange the words positive and negative in the above. After contact with the glass rod the pith ball is positively charged, and hence is attracted by the negatively-charged sealing-wax. In the above it has been assumed that equal quantities of the two kinds of electricity are always produced. This will be referred to later, and experimental proof given (§ 17).

16. The Gold-Leaf Electroscope.—A much more convenient apparatus for detecting the presence of electricity than the pith ball spoken of is a pair of strips of gold-leaf hung from a metal rod inside of a glass jar, the metal rod having a metal disc at the top. This is a sensitive instrument for indicating the presence of electricity and testing its kind; for, on bringing an electrified body over the disc the electricities of the disc are separated, unlike electricity being attracted by the electrified body and like electricity being repelled to the gold-leaves. The leaves accordingly, being similarly charged, repel one another, and therefore diverge. This divergence will be greater the greater the electricity repelled to the leaves; that is, the greater the charge of the body being examined. Thus, the instrument is a detector of electricity.

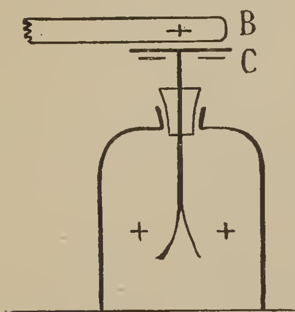


Fig. 1.

Further, it can be used to test the nature of a charge; for, if while it is subject to the inductive influence of a charged body the plate, C, be touched by the hand, the leaves immediately collapse. The explanation of this is, that the charge of the leaves escapes through the hand, while the charge on the plate is still kept " bound " by the attraction of the charged body which is being tested. Then, when the charged body is removed, the charge formerly " bound " on the plate is set " free " and spreads over the leaves also, so that they again diverge, but this time with electricity of the opposite kind to that of the original inducing charge.

Now, to test a charge by the electroscope: Suppose the inducing body, B, was positively charged, then the final charge of the leaves was negative. If, now, a negatively-charged body be brought near the plate, it will repel still more negative electricity to the leaves, and so cause them to diverge still more; but if a positively-charged body be brought near the plate, it will repel positive electricity to the leaves, and so cause them, at first at least, to diverge less. If, however, the positively-charged body be sufficiently strongly charged, it may just repel enough positive electricity to the leaves to neutralize their negative charge, so that they collapse; and then, when brought still nearer, it will repel still more positive electricity to them, so that they again diverge, but this time with positive electricity. Thus, it is the initial movement of the leaves that must be observed.

Hence, when the leaves are left negatively charged, they will expand more when a negative charge is brought near the disc, C, but less when a positive charge is brought near it.

17. Equal Quantities Simultaneously Developed.—By means of the above delicate instrument we can prove the point referred to at

the end of § 15. A flannel cap is made for a rod of sealing-wax. A dry silk thread attached to the cap enables us to turn the cap without touching it. If the rod be turned inside the cap, and then drawn out and presented to the electroscope, it will be found to be negatively electrified; the cap, on being presented to the electroscope, will be found to be positively electrified. But if the rod be turned several times inside the cap and then, without drawing the cap off, both together be presented to the plate of the electroscope, no effect on the leaves is observed. Hence, the two electricities are developed simultaneously and in equal quantities; and this is found to be always so.

18. Electricity Obtainable from All Bodies.—Having shown that as an effect of rubbing in certain cases equal quantities of the two kinds of electricity are obtained, the question arises, Is it only from a limited number of bodies that electricity can be so obtained? Apparently so; for a metal rod rubbed will show no effect on the electroscope. But may it not be always developed by rubbing, and in some way escape our notice? May it not leak away before being noticed? Through what substances will electricity leak? This can be most readily tested by the electroscope: having charged it, touch it with the finger; the charge escapes. Touch it with a metal wire; the charge escapes. Touch it with a dry silk thread; the charge does not escape. Wet the silk thread; it escapes. Try a dry glass tube, it does not escape; try a linen thread, and it does escape. Hence, electricity moves along some bodies, not along others. The former are called *conductors*, the latter *non-conductors* or *insulators*.

This naturally suggests that a metal rod, if insulated and rubbed, would be found electrified. Such will be found to be the case; for, if a brass rod be attached to a glass handle and rubbed, it will affect the electroscope. Electricity, in fact, can be obtained by the friction of any two bodies, though stronger charges will be obtained from some pairs of substances than others.

But we can go farther than this. We can arrange all substances in regular series, a glance at which will tell us what will happen if we rub any two substances in it together. This series is called Volta's contact series. It is such that if any two substances in it be rubbed together, the one that comes higher in the list will be positively electrified and the other negatively. The following will illustrate what is meant:—

+ Catskin.	Cotton.	Sulphur.
Flannel.	Silk.	Gutta-percha.
Ivory.	Metals.	— Gun-cotton
Rock-crystal.	Sealing-wax.	
Glass.	Resin.	

19. Conductors and Non-Conductors.—These are only relative terms. No absolute non-conductors are known and no perfect conductors. But when we have defined conducting power more exactly we shall find a

great difference between substances as regards their conducting powers. Hence bodies that conduct well are called conductors, and those that conduct so extremely ill that under ordinary circumstances they may be regarded as devoid of conducting powers are called non-conductors or insulators.

The following arc conductors: Metals, graphite, flame, linen, cotton, moist bodies generally, etc.

The following are non-conductors: Ebonite, resins, shellac, amber, caoutchouc, dry gases, sulphur, glass, silk, wax, etc.

20. Machines for Obtaining Electricity by Friction and Induction—The Electrophorus.—Having thus the means of obtaining electricity in small quantities, all we need to get a good continuous supply is to apply mechanical devices to working these sources of electricity. Full descriptions of these machines and their treatment will be found under the section treating of "Franklinic Electricity," to which the reader is

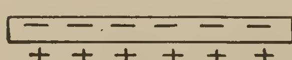


Fig. 2.

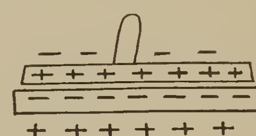


Fig. 3.

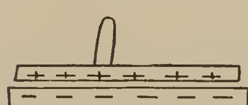


Fig. 4.

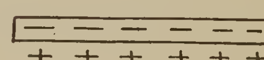


Fig. 5.

referred. The principle on which they are all founded will be readily grasped from the following brief description of the very simplest of them,—the electrophorus.

The electrophorus consists of a shallow pan of metal (called the *sole*) containing a cake of wax (resin or ebonite), and a circular disc of metal of somewhat smaller diameter than the pan, and provided with an insulating handle. This is called the cover. It is used as follows:—

(1) The cake is dusted with a piece of flannel, after which the surface of the cake is found to be negatively electrified, and by induction a positive charge is drawn to the metal of the sole. (Fig. 2.)

(2) The cover is now brought down on the cake, and thereby a positive charge is induced on the metal cover. (Fig. 3.)

(3) The cover is now touched with the finger, whereupon the repelled negative charge of the cover escapes. (Fig. 4.)

(4) The cover is now removed and carries away a positive charge with it, leaving the cake exactly in its first condition, making allowance for a slight amount of leakage of its charge that has nothing to do with the process. (Fig. 5.)

All we need to do now is to mount the cover and sole on rotating plates in such a way that when the plates are rotated, by hand or otherwise, the cover is brought into the presence of the sole, touched, to carry

away its repelled charge, and then carried around to another body, to which it imparts its charge, and again brought around in front of the sole. Thus we shall have a *continuous electrophorus* yielding supplies of both kinds of electricity.

An important point may be noticed in the foregoing description. The charged cover when removed contains a stock of energy, as is shown by the noise and sparks it will yield on giving up its charge to another body. Whence came this energy? Not from the cake, for its charge is not at all diminished by the operations. To produce energy work must be done or energy expended. The source of the energy of the charged plate is the *extra* work that must be done, in lifting the cover away from the oppositely charged cake, over and above what would be done if the cake were not charged. Similarly, in a continuous machine more work is done in rotating the parts when the machine is charged and working than would be done if the machine were not charged, and this extra work is the source of the energy.

The above must not be understood as implying that electricity is energy. It is not, though electrification is. But, of this later.

FIG. 6.

21. DISTRIBUTION OF ELECTRICITY ON CONDUCTORS.—On a non-conductor electricity remains where developed, but on a conductor it spreads itself, though not uniformly. The charge on a small part of the surface is greater the more curved it is. The charge per unit of surface is what we define as the *surface density* of the electrical distribution. It will be noticed that we speak only of the surface density, and in truth this is all that we need speak about, for electricity resides only on the surface of conductors. No charge whatever can be detected, except on the surface. The charge of electricity a conductor will accept depends in no way on how the interior of the conductor is constituted, whether it be hollow or filled in any possible way. This can be shown in many ways. Biot showed that when a ball is charged and covered by two metal hemispheres with insulating handles, then, after the hemispheres have touched the ball and been removed, no charge remains on the ball. Faraday proved it by showing that if a small, conical net be charged and then turned inside out by means of a silk thread through the vertex, the charge always resides on the outside.

22. THE STATIC UNIT OF ELECTRICITY.—Electricity is that which produces certain attractions and repulsions, and is to be therefore defined in terms of the force of these attractions and repulsions. Let us think of two equal quantities of positive electricity at two points a unit dis-

tance apart, and let these quantities be such that they repel each other with a unit of force. Then, either of these we shall take as our unit of electricity; or, the static unit of electricity is such a quantity that when at unit distance from another equal quantity it repels the latter with unit force.

23. The Electrical Field.—An electrical field is the portion of space in the neighborhood of electrified bodies considered with reference to electrical phenomena. At every point in an electrical field there is an electrical force,—*i.e.*, a small charge of electricity introduced there would be urged with a definite force in a definite direction. The force with which a positive unit would be urged is called the electrical force or the field-strength at that point. To specify fully the force at a point in the electrical field, we must give both the magnitude of the force and its direction. If, starting from any point, a curve be drawn following everywhere the direction of the electrical force at the points through which it passes, such a curve is called a line of electrical force; or, a line of electrical force is a line whose direction at every point is that of the electrical force.

24. Potential.—The conception of potential is one of the most important in the treatment of electricity. Unfortunately, it is also one that has acquired the reputation of presenting considerable difficulty to the uninitiated. This evil reputation it probably owes to a certain confusion in the way in which it is frequently explained. To understand it clearly we must remember clearly the difference there is between the *idea or meaning* of a physical property and its *measure*. The idea can be but one, though the modes of measurement may be many.

To make clear what we mean let us think of the word mass. By the mass of a body we mean simply the quantity of matter it contains. But when we proceed to measure the mass we may employ several methods. We may compare masses by comparing the speeds that a certain force —say, a stretched elastic string—drawing them along a smooth horizontal table will get up in them. Then, by a well-known law due to Newton, the masses are inversely as the speeds thus produced by the same force. Again, we may compare the masses by comparing the forces with which they are attracted by the earth. Thus we measure them by weighing them in a balance. These methods lead to the same result, and are therefore consistent. Others might be given, but these will suffice to make clear the distinction referred to.

Let us take another and more closely parallel case, viz., temperature. The idea of temperature is simply this: Of two bodies, that is said to be at the higher temperature which will yield up heat to the other when the two come into contact; or, temperature is that quality which determines the direction of flow of heat when two bodies are put in contact. Now, we may *measure* this property in various ways,—*e.g.*, the higher the temperature of a mass of mercury, the greater is found to be its volume.

Hence we compare temperatures by the height to which mercury rises in a closed tube. This is the method of the mercury thermometer. Again, if we take a spiral spring made out of a ribbon, consisting of a strip of platinum and a strip of silver, it will be found that the higher its temperature the more it will untwist, and so turn a light needle, which will indicate the temperature. Thus, temperature bears but one meaning, but the property can be measured in different ways.

The idea of potential is like that of temperature, viz., the quality that determines the direction of flow of positive electricity when two charged bodies are brought into communication by a conductor. The one from which the positive electricity flows is said to be at the higher potential.

The measure of potential usually adopted can be best made clear by the aid of another analogy. Potential of electricity is like the level of water. The level of water is that which determines in what direction water will flow when two vessels are put into communication, the surface being at the higher level in the one from which water flows. Now, it is true that we have a foot-rule method of measuring difference of level. But without the foot-rule we might have measured it in this way: When a pound of water is raised from a lower to a higher level the attraction of the earth is overcome through a certain distance and work is done, the measure of the work being the product of the force overcome and the distance, so that for different differences of level the work done is proportional to the difference of level. Thus, if we had an instrument for measuring the work we could in this way measure the difference of level.

Now, electricity is an invisible thing, not material,—at least, in the ordinary sense of matter; so that we cannot apply anything like a "foot-rule" method to measuring differences of potential; but we can apply the work method, and then we give the following definition: The measure of the difference of potential of two charged bodies is the work that would have to be done in carrying a unit quantity of positive electricity from the one of lower to that of higher potential.

To understand this definition clearly, there are several things to notice about it. In the first place, it implies a unit of difference of potential, namely, unit difference of potential is the difference of potential that exists between two charged bodies when unit of work is required to carry unit of positive electricity from one to the other. In the second place, it will be noticed that we have spoken only of *differences* of potential. In fact, this is all we have to deal with, just as it is only with difference of water-level that we have to do, though some standard level or starting-point for the measurement of level may be most convenient. In the case of water, the starting-point usually taken is the level of the sea. Similarly, the most convenient practical starting-point in measuring differences of potential is that of the earth or anything in electrical

communication with it. Hence, the practical zero of potential is that of the earth. But there is a theoretical or absolute zero of potential employed in the mathematical treatment of electricity, namely, the potential at an infinite distance away from a charged body. This absolute zero, however, need not be employed in this work, just as the practical zero of temperature—that of melting ice—suffices for all practical purposes, though an absolute one is employed in theory, being about 273° C. below zero. Further, it will be noticed that the above definition applies, no matter what unit of electricity is employed. Now, some slight confusion and difficulty are caused in electricity by the fact that two different units are at different times employed. One we have explained (§ 22); the other, and more important one, we will explain later.

Finally, though the above definition applies only to the difference of potential between two charged bodies, it need not be limited to two charged bodies, but may be made to apply equally to two points. It is evident that if two points are in the neighborhood of charges,—*i.e.*, are in an electrical field (§ 23),—work will be needed to carry electricity from one to the other, and they will therefore be at different potentials. Hence we shall often have to speak of the differences of potential *between points.*

25. Capacity.—If we put an insulated conductor close to the discharging knob of an electrical machine supplying, say, positive electricity, the knob will, for a time, discharge positive electricity to the conductor, but will soon cease to do so. But if we now bring the conductor equally near to another machine giving electricity at a higher potential, a further charge will be imparted to the conductor. In fact, with a source of electricity at a given potential there is a certain maximum charge that can be given to a conductor, for no more can be imparted when the charge on the conductor has risen to the potential of the source. How much electricity is required to raise the charge on a conductor to a given potential depends on the capacity of the conductor. The capacity of conductors corresponds to the breadth of jars containing liquids, for it is the breadth that determines the amount of liquid requisite to fill a jar to a given level. Hence we define the capacity of a conductor as the quantity of electricity requisite to increase its potential by unity.

Fig. 7.

26. Condensers.—A condenser is simply a means employed to increase the capacity of a conductor, *i.e.*, a means of getting a larger charge on the conductor, the potential of the source being unchanged. If the conductor mentioned in the last paragraph be a circular disc of metal, A, and if a second similar one, B, connected with the earth, be brought near the first, but not so as to touch it, it is found that the

first one will receive a much greater charge than previously from a source at the same potential. This combination of two plates with an insulator (in this case air) between them forms a plate-condenser (Fig. 7).

The effect of the second plate, B, can be explained thus : The potential of A being raised, A tends to raise the potential of B; but B remains at the potential of the earth, since it is connected with it by a conductor. Hence, negative electricity must flow to B from the earth; so that the negative potential so caused may just neutralize the positive potential that A would cause, and would leave B at zero potential. The negative potential thus produced by B's negative charge then reacts on A, tending to lower its potential, but its potential does not fall, being the same as that of the terminal of the machine. Hence, more electricity must flow to A from the machine to keep its potential up. Thus the effect of the second plate is to enable A to receive a larger charge, *i.e.*, to increase its capacity.

27. Dielectrics and Inductive Capacity.—The above interaction between A and B is, of course, only possible when the medium between A and B is non-conducting. A non-conducting or insulating medium between two electrified conductors is called a *dielectric*. In the above case it was air, but it might have been glass, ebonite, or any other insulator whatsoever. We should find, however, a difference between different dielectrics. For equal thicknesses of the dielectric, glass as a dielectric would give a condenser of three times the capacity that air would, and solid paraffin two times. This quality of an insulator that determines the capacity of a condenser in which it is employed as dielectric is called its *inductive capacity*.

To be more precise, we must assign a method of measuring the property called inductive capacity. It can be done in this way : Determine the capacity of a condenser in two sets of circumstances,—first, with air as its dielectric ; second, with, say, glass as its dielectric. Divide the capacity of the condenser in the latter case by its capacity in the former, and the ratio is called the specific inductive capacity of the glass. The ratio so determined will be found to be the same, no matter what shape or size of condenser is employed. It depends only upon the dielectric. Hence, the *specific inductive capacity* of a dielectric is the ratio of the capacity of a condenser with that substance as dielectric to that of another exactly similar but with air as dielectric.

Note.—The reader must be careful not to confuse the terms *capacity of a condenser* (§ 25) and *inductive capacity of a dielectric*.

28. Forms of Condensers.—It is evident from § 26 that, if the thickness of the dielectric of a condenser be decreased, the inductive effects will be increased, and so the capacity of the condenser increased. Again, it is evident that increasing the area of the plates will also increase the capacity of the condenser. Hence, on the whole, the capacity of a condenser is proportional (1) directly to the area of the plates ; (2)

inversely to the thickness of the dielectric; (3) directly to the specific inductive capacity of the dielectric.

Condensers are made in many forms. The usual dielectric is glass, for its specific inductive capacity is particularly high. The jar form of condenser is the most common and most convenient. It is simply a glass jar coated with tin-foil two-thirds of the way up, inside and outside, and closed with a cork, through which a metal rod passes carrying a knob at the upper end, and connected at its lower end with the internal coating. To charge it, the knob is connected with a machine and the outer coating with the earth. It will thus charge to the potential of the machine; but if the latter be too high, the glass is apt to be broken by a disruptive discharge through it. Such condensers are used in connection with the terminals of machines to enable them to store up larger quantities of electricity, and thus cause a larger discharge. (*Vide* also section on "Franklinic Electricity.")

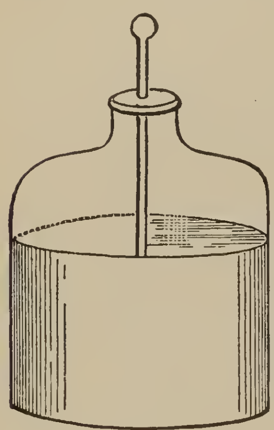


Fig. 8.

29. Seat of Charge and Residual Charges.—At the end of this section we shall make a short attempt to explain what electricity is, and so we state here a few facts as to the action of Leyden jars that bear on that point. If a jar be made with stiff, removable coatings and charged, it will be found, on removing the coatings, that no charge really resides on them; and yet, on restoring them and discharging the jar, the original charge will be reproduced. Such, however, will not be the case if the glass of the jar be thoroughly discharged by passing it through a flame while the jar is apart. Hence the charge, whatever its nature, really resides in the dielectric.

Again, after an apparently complete discharge of a jar a residual charge is slowly developed, as may be seen by again discharging it, whereupon a small discharge will be obtained. This has been described as a "soaking" of the electricity "into" the dielectric, and a subsequent "soaking out." Its real nature will be discussed later.

Again, every charge has its corresponding residual charge and discharge; so that if several charges be given to a jar, the charges being either of the same or of different kinds, all the residual charges can be obtained, but in the opposite order to the order of the original charges. This is an exact parallel to certain phenomena obtained by twisting an elastic rod. If such a rod be twisted, and then allowed to gently untwist, it will not do so completely, but will retain a residual twist and will show a residual untwisting. Moreover, if the rod be given several such twists,

whether in the same or in opposite directions, corresponding residual twists and untwistings also take place in the opposite to the order of the original twists.

Now, these latter are due to elasticity in the rod; and the similar action of the Leyden jar, taken together with what was stated as to the seat of the charge, suggests that electrification is an elastic phenomenon of the dielectric, or of something associated with it. Of this, later.

Magnetism.

30. We turn now to certain other phenomena long thought quite distinct from the preceding, but which fundamentally are closely allied. We shall take them up from the point of view of this connection. If a copper wire be bent into a spiral around a glass tube covering a steel rod, such as a knitting-needle, and a charge of electricity—say, from a Leyden jar—be passed through the spiral, the steel rod will be found to

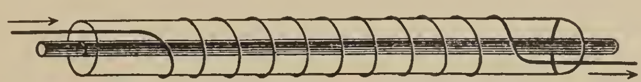


Fig. 9.

have acquired certain new properties. These properties are called magnetism, and the rod is called a magnet. The properties are these:—

(*a*) If freely suspended in a horizontal plane, the magnetized needle will take up a definite nearly north and south direction, to which it will return after being disturbed. The end pointing nearly north is called the north-seeking pole of the magnet, the other the south-seeking pole.

(*b*) If two such needles be suspended near each other, it will be found that like poles repel each other and unlike poles attract each other.

But these two properties are not distinct. The first to show this was Gilbert, of Colchester ("the Galileo of Magnetism"), who lived in the sixteenth century. For the earth itself is a magnet, and consequently acts on other magnets according to (*b*). The magnetic action of the earth can be fairly well represented by imagining a great magnet, about half the earth's diameter in length, buried, with one end below Boothia Felix, in the north of Canada, and the other at the opposite point in the southern hemisphere. It will now be seen that if we call that pole of this great earth-magnet which lies in the northern hemisphere the magnetic north pole of the earth, we should properly call the north-seeking pole of a magnetic needle a true south pole, and the south-seeking pole a true north pole. But custom is quite inconsistent in this matter; so we shall have to adhere to the terms north pole and south pole of a magnet, meaning thereby north-seeking and south-seeking, respectively.

31. Magnetic Induction, Temporary and Permanent.—Supposing that in the preceding way a magnet has been produced, we can from that magnet make others, as follows: Take another unmagnetized steel

needle and stroke it from end to end, always in the same direction, with the north pole of the magnet. It will be found that the unmagnetized needle has become magnetized with a south pole at the end which the north pole of the magnetizing needle last touched. In this way any number of *permanent* magnets can be made by induction.

But *temporary* magnetism can also be induced. Of this we have an example in the familiar experiment of shoving a pole of a magnet among soft-iron filings, whereupon the filings cling to the pole. This is simply due to the fact that the iron particles become, for the time being, magnets attracted by the inducing pole and attracting each other; but immediately the inducing magnet is removed they cease to attract one another; their magnetism is gone. This merely temporary induction of magnetism in soft iron is of great importance. It will be noticed that the difference is that hard iron or steel is susceptible of permanent magnetism, soft iron of merely temporary magnetism.

The oldest known example of induction is the inductive action of the earth's magnetism on a certain compound of iron called magnetic iron-oxide, giving rise to the lodestone, which is supposed to have been named magnet from being found in Magnesia, in Asia Minor. Being itself a magnet, it can be used to magnetize a needle, and in this way the first mariners' compass was produced. There seems little doubt that the Chinese knew and used this property four thousand years ago (see Sir Wm. Thomson's "Popular Lectures," vol. iii, "Navigation").

32. Unit Magnetic Pole; Laws of Magnetic Attractions and Repulsions; Magnetic Field.—The definition of unit pole is like that of unit charge of electricity, viz., unit magnetic pole is that which at unit distance from an equal similar pole repels it with unit force. Having thus defined unit pole, the laws of magnetic attractions and repulsions may be stated thus:—

(*a*) Like poles repel one another, unlike attract.

(*b*) The attractions and repulsions are proportional to the strength of the poles.

(*c*) The attractions and repulsions are inversely proportional to the square of the distance between the poles.

These are the same as for quantities of electricity, and need not be enlarged on.

A magnetic field is the portion of space in the neighborhood of magnetized bodies considered with reference to magnetic phenomena. The strength of the field at any point is the force with which the field would act on a positive unit pole at that point. A line of magnetic force is a line whose direction at every point is that of the direction of the magnetic force. Magnetic potential will probably not be referred to in the sequel; so all that need be said of it is that it is measured like electrical potential (§ 24).

33. Astatic Combination of Magnetic Needles.—Any freely-suspended needle is subject to the directive force of the earth. If a quite

similar needle be attached to it so that similar poles point in opposite directions, and the combination be freely suspended, the needles will, under the earth's influence, tend to turn in opposite directions; and if the needles be perfectly similar and of equal strength, the earth will exercise no directive force on the combination,—or, it will be astatic. But as it is practically impossible to get a perfectly similar pair of needles, we must content ourselves with a nearly astatic combination; that is, a combination on which the earth exercises but a very feeble directive force. Such a combination is useful for purposes that will be stated later.

34. Facts Bearing on the Nature of Magnetism—Molecular Theory.—If a magnet—say, a magnetized piece of watch-spring—be cut in two, it will be found that each piece is a magnet with two opposite poles. The same holds true no matter how often we may cut a magnet up or how small particles we may reduce it to. Hence, magnetism is a property of the ultimate particles of a substance.

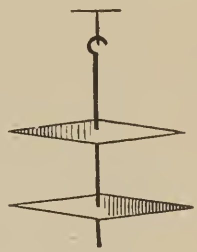


Fig. 10.

In an unmagnetized needle these little molecular magnets lie higgledy-piggledy,—in all directions,—and magnetization consists in turning them so as to face in the same direction. When a piece of iron is fully magnetized or saturated,—*i.e.*, has received the full measure of magnetism it can contain,—all these molecular magnets have faced in the same direction; when magnetized below saturation, some have wheeled around and some have not, or all have wheeled around, but not the whole way. Thus, in the body of a magnet, each north pole will be neutralized by an adjacent south pole belonging to a neighboring molecule. The unneutralized north poles at one end give a north pole to that end of the bar, and the unneutralized south poles at the other end a south pole there. This is the molecular theory of magnetism.

Some facts bearing on it may be mentioned. It is evident that on this hypothesis magnetization should be facilitated by anything that tends to set the molecules in motion; and on the other hand, after the magnetizing agent has ceased to act, demagnetization should be accelerated by the same means. This is found to be so. Hammering, twisting, and bending tend to set the molecules free, and thus aid magnetization or demagnetization, as the case may be. Moreover, heating, which consists in giving more vigor to the molecular motions (§ 10), also assists in a similar way.

Again, if such a wheeling into line actually takes place, we might expect to find a change in the length of a bar on being magnetized. This is a well-marked phenomenon amounting in certain cases to $\frac{1}{200000}$ of the whole length of the bar.

Finally, strong support is given to the theory by the action of a

model, consisting of a large number of small magnetic needles, constructed recently by Ewing. This would not be the place to go into details. Suffice it to say that the most of the peculiar stages of magnetization and demagnetization of a bar are imitated by his molecular model.

Kinetic (or Voltaic) Electricity.

35. Currents of Electricity.—We proceed now to consider the properties of streams or currents of electricity. But it will be understood that the electricity we have to do with differs in no way in kind from that which we have already treated of, though it does differ at first sight as regards method of production, and certainly differs greatly in potential and quantity. Static electricity as produced by the machines referred to in § 20 is electricity at very high potential, but very small in quantity. The electricity we get by the contrivance described below is electricity at very low potential, but in large quantities. Or, if we compare the stream of electricity between the knobs of a statical electrical machine and the current of electricity produced by a voltaic pile, the difference between them is like that between a lofty water-fall down which a small stream falls and a broad, slow river of small pitch. In both of the latter cases it is water, and so too in both of the former cases it is electricity.

Volta's cell for procuring a current of low-potential electricity is this: Take a zinc and a copper plate, connect them by a wire and dip them into water containing a small proportion of sulphuric acid. Immediately bubbles will begin to be given off from the copper plate. Moreover, a new property has been conferred on the wire; for if it be wound in a spiral around a glass tube containing a piece of soft-iron wire, it will be found to make the latter temporarily a magnet; hence a current of electricity is passing along the wire. But this method of showing the presence of a current is one far from satisfactory or handy; so we must proceed to explain a much better one.

36. Indicator of Current; Oersted's Principle; Galvanometer.—The following connection between a current of electricity and a magnet discovered by Oersted goes by the name of Oersted's principle, viz., a freely-suspended needle in general is deflected by the passage of a current of electricity in its neighborhood. This may be readily tested by an electrical machine and a freely-swinging needle. On sending positive electricity from *south to north* over the needle it will be found to deflect with its *north end west*, and reversing the direction of the current, or changing from above to below, will reverse the direction of the deflection. The direction of the deflection will always be given by the following rule: Suppose yourself swimming in the current and facing the needle, then the north pole will be deflected to your left hand. This is Ampère's rule. A simpler one is: Place your right hand on the current with the palm toward the needle, then the north pole of the magnet will be deflected in the direction of your thumb.

A sensitive needle will thus serve to detect a current of electricity. But we can greatly increase the sensitiveness of the test as follows: Instead of using a single straight portion of the wire, let us make a circular coil of part of it and put the needle at the centre of the coil, and in its plane. Then each part of the current will act on the needle, and, since the current circulates several times around the needle, the effect will be correspondingly multiplied. Such a contrivance was originally called a multiplier, but it is identical in principle with the present-day galvanometer.

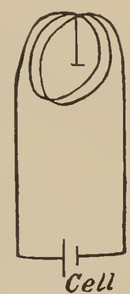


FIG. 11.

To render small deflections of the needle visible several devices have been employed. Sometimes a long, light pointer (say, of aluminium) is attached to the needle. The motion of the end of the pointer is greater in proportion to its length than that of the needle, and so small deflections are made more evident.

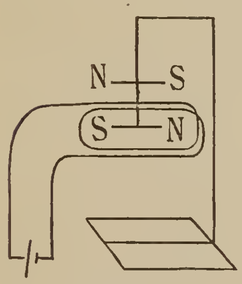


FIG. 12.

A much more effective device, due to Poggendorff, is to attach a very light mirror to the needle and allow light to fall on the mirror and then be reflected to a somewhat distant scale. It is a simple matter of geometry to show that the direction of the reflected ray is turned by the motion of the mirror through twice as great an angle as the mirror is turned through by the passage of the current. This is what is known as *Thomson's reflecting galvanometer*.

Another means of making the galvanometer a more sensitive detector is to use an astatic combination of needles (§ 33), letting the current circulate around one of the needles only. Thus, the earth's directive force being greatly reduced by the pitting of one magnet against the other while the directive force of the current is undiminished, since it acts on one needle only, the astatic pair will answer much more sensitively to the passage of a current. This gives us the *astatic galvanometer*. Or, a single needle may be used and the earth's directive force counteracted by a large, stationary, compensating magnet, M, producing a field in the opposite direction to the earth's field. By this device the mirror can be turned so as to reflect in any desired direction. Such means as these give very sensitive instruments for detecting the presence of currents.

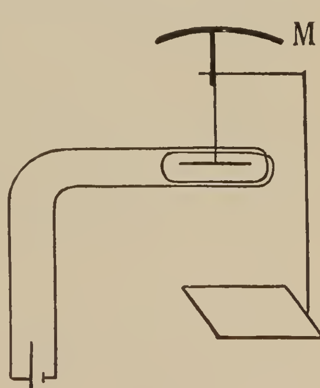


FIG. 13.

37. Volta's Cell.—If the plates of Volta's cell, described in § 35, be connected with the ends of the galvanometer coil, an immediate deflection of the magnet announces the passage of a current of electricity. If instead of a galvanometer a simple needle be used, a straight portion of the circuit carrying the current being held over it, it will readily be seen, from the direction of the deflection of the needle, taken along with the

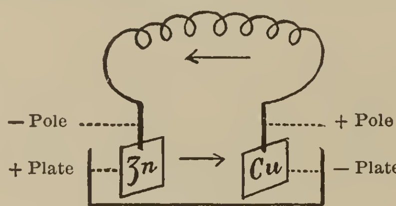


Fig. 14.

rules given in § 36, that the positive current goes from the copper plate along the wire to the zinc plate, and thence from the zinc plate in the liquid to the copper plate. (As a *memoria technica*, the rule *zinc in liquid to copper* may be shortened to *z-in-c*,—spelling the word zinc.)

Terminal wires or binding-screws are usually attached to the plates. Now, considering the external part of the circuit (*i.e.*, the part out of the liquid), the positive electricity passes from the *terminal* of the copper plate to that of the zinc. Hence the copper terminal is called the positive pole and the zinc terminal the negative pole. Considering now the part of the circuit *in* the liquid, the current passes from the zinc plate to the copper plate. Hence the zinc is called the positive *plate* and the copper the negative plate. If this be kept in mind, no confusion need be caused by the paradox that the positive pole is the terminal of the negative plate and the negative pole the terminal of the positive plate.

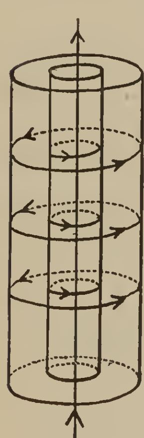


Fig. 15.

The evolution of gas at the copper plate shows that some chemical reactions are going on in the cell. What is really taking place is, that the sulphuric acid is acting on the zinc, thus:—

$$Zn + H_2SO_4 = ZnSO_4 + H_2$$

So that hydrogen is set free, and this is the gas that is appearing at the copper plate. The zinc sulphate that is formed remains in the liquid, while the zinc is gradually eaten away. This is the simplest possible form of voltaic cell.

38. Magnetic Field of Force of a Current.—Wherever a magnet is subject to magnetic force there is, by § 32, a field of magnetic force. Hence a current has a magnetic field. It is a comparatively simple problem to determine the direction of the lines of force of this

field, *i.e.*, the direction of the force at any point in the field. A magnet tends everywhere to set itself at right angles to the current, no matter on which side of the current it is. Hence, the lines of force are circles surrounding the current with their centres on the current. They may be thought of in this way: Imagine the current surrounded by circular cylinders, the current occupying the axis. Then the lines of force are circles, got by taking sections of the cylinder at right angles to the axis. The direction of the force along these lines of force relatively to the direction of the current may be found by Ampère's rule (§ 36), or it is more simply remembered from the rule that the direction of the current is related to the positive direction of the lines of force, as the thrust to the twist in a right-handed screw.

39. Electro-magnetic Units of Current and Quantity.—We have already stated the action of a current on a magnetic needle. Suppose, now, we take a wire in which a current is flowing and bend it into a circle. Let the circle be one of unit radius. Think, now, of a part of this current of unit length. It will exercise a certain force on a unit magnetic pole at the centre of the circle. What force it will so exercise will depend on the strength of the current. The unit of current that we adopt is the current which, under the above circumstances, will exert unit force on the unit magnet-pole at its centre. Or, to sum up the definition, the electro-magnetic unit of current is a current unit length of which bent into an arc of a circle of unit radius exerts unit force on a unit magnetic pole placed at the centre. If the C. G. S. units (§ 11) be employed, this is called the absolute electro-magnetic unit of current. In practice, however, a current equal one-tenth of the absolute unit of current is employed as unit, and is called the *ampère*. The electro-magnetic unit of quantity is the quantity that is conveyed by unit current in unit time. The practical unit of quantity is only one-tenth of the absolute unit, and is called the *coulomb*.

40. Electro-motive Force.—When matter is set in motion or has its motion kept up in spite of resistance, we say the effect is due to a force. When a current of electricity is started or kept up in spite of resistance, we refer this effect to a force moving the electricity, or an electro-motive force. Hence, we define electro-motive force as whatever sets up or keeps up a current of electricity.

The usual cause of a flow of electricity is a difference of potential. (For a careful account of what is meant by differences of potential see § 24.) Hence, potential difference is the usual electro-motive force; but it is not the only form. Just as in the case of water the usual cause of flow is a difference of level,—but flow may be produced by other causes, such as a force-pump,—so also, in the case of electricity, other forms of electro-motive force than potential difference are known.

Now, we can readily define unit difference of potential, and we shall take the same as our definition of unit electro-motive force generally.

There is no inconsistency in this,—although electro-motive force is not always due to difference of potential,—just as there is no inconsistency in describing the pressure produced by a force-pump in a water-pipe as equivalent to a "head" of so many feet, although there may be no actual difference of level.

Hence, we shall take the unit of electro-motive force as simply the same as the unit difference of potential. The reader is therefore recommended to carefully master § 24, dealing with potential. Then, adopting the electro-magnetic unit of quantity, we define as follows: Unit difference of potential or unit electro-motive force exists between two points when it requires the expenditure of unit of work to bring a positive unit of electricity from one point to the other against the electro-motive force.

This absolute unit would be far too small. Hence the practical unit, called the volt, is taken as equal to one hundred million (100,000,000) absolute units. Although the electro-motive force of Volta's simple cell (§ 35) is not always quite the same, yet, roughly speaking, it is about a volt.

41. Resistance.—If we take the Volta cell, described on page 22, and pass the current produced by it through wires of various lengths, thicknesses, and materials, including a galvanometer in the circuit, we shall find that the current produced varies with all three of these conditions, viz., that the current is weaker the longer the wire, is also weaker the thinner the wire, and is weaker for some materials than others, even with the same size of wire. For the same length and thickness, it will be found that the current through copper wire is greater than that through an iron or a platinum one. Hence we say that iron and platinum offer a greater resistance to the current than copper does, and that long or thin wires of any material offer greater resistance than short or thick wires of the same material.

To keep this matter clear, we may remember the analogy of water passing through pipes. The longer the pipe, the greater the frictional resistance, and, the narrower the pipe, the greater the frictional resistance. Finally, with pipes of the same size, the resistance will depend somewhat on the material of the pipe. We conceive electrical resistance to be somewhat of the nature of frictional opposition to the current.

The greater the resistance of a conductor, the smaller the current that a given electro-motive force can force through it. Hence we define the unit of resistance in terms of the units of electro-motive force and current, and we say that a conductor has unit of resistance when unit difference of potential between its ends causes unit current to flow through it. If we use the absolute units of current and potential difference (or electro-motive force) this definition, of course, gives us the absolute unit of resistance. The practical unit is much larger, containing 1,000,000,000 absolute units, and is called the *ohm*. It is the resistance

of a column of mercury 1 millimetre square and 106¼ centimetres long. For convenience we tabulate these three important practical units thus :—

Unit of	called the	roughly is that of	and contains — absolute (C. G. S.) units
Current	ampère	——	one-tenth
Electro-motive force	volt	a simple Volta cell	a hundred million
Resistance	ohm	a column of mercury 1 mm. square and 1 metre long	a billion

42. Defects of the Simple Cell of Volta.—The requirements of a good Voltaic cell are so numerous that all can hardly be satisfied at once. The electro-motive force should be high and constant. Neither part of this condition is well fulfilled by Volta's simple zinc-copper cell. Its electro-motive force is not high as cells go, and not at all constant. The chief cause of its falling off in electro-motive force is what is called *polarization*, *i.e.*, a change in the surface of the plate produced by the deposition of the products of the decomposition in the cell; in this case the substance deposited is hydrogen-gas on the copper plate, by which the surface of the plate is altered; so that we have really a different plate to deal with.

The other chief defect of the simple Voltaic cell is excessive *local action*, as it is called. By this is meant a local and useless consumption of the plates apart from the consumption necessary to produce the electric current. In the present case it takes the form of a gradual consumption of the zinc plate owing to impurities or irregularities in the plate. Wherever in the zinc a foreign particle (say, of iron) is exposed, there we have a little local battery formed by that particle, the fluid, and the adjacent parts of the zinc itself, and thus the zinc is consumed without this consumption adding to the main current. The same effect is produced by mere irregularities and inequalities in the zinc itself, for two parts of the zinc plate with slightly different physical qualities (*e.g.*, hardness) will act as separate metals, again giving rise to local action.

Local action may be got rid of by "amalgamating" the zinc plate, as it is called, *i.e.*, by giving it a surface-covering of an amalgam of zinc and mercury. This is done by first cleaning the plate with dilute sulphuric acid and then rubbing mercury over it. If the plate is one of smooth-rolled zinc it will at once take on a bright coating of zinc amalgam. The zinc consumed in the production of the current is removed from the amalgam and its place taken by fresh zinc from the plate below the coating. The action is thus rendered uniform over the surface of the plate, and any foreign particles in the zinc are brought to the surface of the

amalgam and carried away by the hydrogen bubbles. In the use of batteries containing zinc plates care must be taken to see that the zinc is kept properly amalgamated. If a battery is used daily new zinc may need to be amalgamated daily for four or five days, but after that once a week or fortnight will suffice.

To describe the remedies for polarization we would have to describe the various modifications of Volta's cell now employed. For this the reader is referred to the separate section on "Voltaic Electricity."

43. Controversy as to the Action of the Voltaic Cell.—Nearly ever since the invention of the voltaic cell a spirited warfare has been waged between two schools of physicists,—viz., the "contact" and the "chemical" schools,—as to the method of action of the cell. As in all such cases where the opponents are honest in the positions assumed, the truth probably lies between the two extremes. To make the matter plain, however, we shall state the extreme positions.

The older or contact theory is this: (1) on joining two metals, either directly or by a wire, a difference of potential is observed; (2) when the metals still joined are immersed in a liquid which acts upon one more than the other, the chemical action equalizes the potentials, and in so doing causes a flow of electricity along the connecting wire; (3) the moment the equalization of potential has commenced the difference is renewed again at the point or points of contact between the metals, and so, if no disturbing cause interfere, a continuous flow of electricity is kept up until the metal most acted on is entirely dissolved. (Gordon.)

Here, it will be noticed, the primary point emphasized is the difference of potential produced by the mere contact; but it is not claimed these differences alone will produce a current. A current will only be produced when some extraneous means—*e.g.*, chemical actions—are employed to keep up the difference. If the mere contacts without chemical reaction could produce a current there would be a constant supply of fresh energy with no corresponding disappearance of energy from elsewhere, and a consequent violation of the law of conservation of energy. Now, in a circuit consisting only of metals, all at the same temperature, no chemical actions will be observed. Hence, according to the law of the conservation of energy no continuous currents can be produced,—*i.e.*, there can be no resultant electro-motive force. To put it in the concrete: Suppose we have a circuit of three metals, a, b, c,—${}_{c}\overset{a}{\bigtriangledown}{}_{b}$,—and suppose we call the electro-motive forces at the contact, respectively, F_{ab}, F_{bc}, F_{ca}, reckoning them all in the same direction, then, since there is no current,

$$F_{ab} + F_{bc} + F_{ca} = 0;$$

and the same will be true, no matter how many different metals may be included in the circuit.

We can put the above in another way; in fact, the way in which it

was originally put by Volta himself. Of course, the electro-motive force from a to c is equal, but of opposite sign to that from c to a; or, $F_{ac} = -F_{ca}$. Hence, from the above equation,

$$\begin{aligned} F_{ab} + F_{bc} &= -F_{ca} \\ &= F_{ac}; \end{aligned}$$

or, we get the same electro-motive force from a and c directly on contact as when we insert any other or, in fact, any number of other metals between them. This bearing of the conservation of energy on the question was not considered by Volta's followers, and so they were led into statements which caused Faraday to altogether deny the existence of contact electro-motive forces, and to refer the whole thing to the chemical actions.

The position assumed by the chemical theory, with which Faraday's name is associated, is this: (1) when two plates are placed in the liquid, but not in contact, they are brought to different potentials; (2) if they be then connected by a wire, electricity rushes along the wire to equalize the potential of the plates; (3) and since this difference of potential is constantly renewed, there will be a constant flow of electricity till the plate most acted on is consumed.

Those who maintain the chemical theory also do so now in a modified form. While maintaining that the chief seat of electro-motive force is the Zn-liquid junction, they admit a real, though they claim comparatively slight, potential difference at the metal contacts. The real existence of this potential difference at metal contacts has been shown by Thomson, and is evident from the facts of thermo-electricity.

The advocates of the contact theory do not attempt to explain the cause of the contact forces. The advocates of the chemical theory advance a reasonable explanation of the potential differences produced at the zinc-acid junctión. It is this: The liquid in contact with the plates contains atoms, some charged positively, some negatively,—say, oxygen, every atom of which has a certain negative charge; and hydrogen, every atom of which has a positive charge. Both the Zn and the Cu plates attract oxygen, as is shown by their readiness to rust or oxidize. But the zinc attracts oxygen more strongly than does the copper. Now, in the liquid there are, at a certain moment, a goodly number of free atoms (§ 6), for some of the molecules are always breaking up and immediately recombining, with an interchange of atomic partners. The distance at which zinc will exert any appreciable attraction on an oxygen atom is very small,—say, one-ten-millionth of a millimetre,—and this is called the molecular range. The Zn plate, then, acts on all momentarily free atoms of oxygen within molecular range of it, attracting them to itself. But their place in the thin sheet of liquid near the plate, whose thickness is the molecular range, will then be immediately taken by other free atoms coming in by diffusion from more distant layers, and thus the

supply of oxygen atoms is kept up, and there will be a gradual procession of oxygen atoms through the liquid toward the zinc,—at a rate determined by the electro-motive force acting and the rate of diffusion natural to the liquid employed. Now, all the oxygen atoms that reach the zinc, each with its negative charge, neutralize a certain portion of the positive electricity of the zinc, and thus leave it charged negatively. If no channel be afforded for the escape of this negative charge, it soon becomes so large as to repel the similarly-charged oxygen atoms with as great a force as the zinc naturally attracts them, and then the process ceases.

44. Ohm's Law.—The basis of exact measurements in electricity is a famous law published by Dr. G. S. Ohm in 1827,—a law that has stood the test of numerous keen examinations since, and now deserves to rank with the laws of gravitation and of electro-static attractions and repulsions as a real law of nature.

Ohm's law is that the current produced in a conductor by an electromotive force is proportional directly to the electro-motive force and inversely to the resistance of the conductor; or, C is proportional to E divided by R, which is written in mathematics thus :—

$$C \propto \frac{E}{R}$$

Such a proportion is equivalent to an equation into which a constant numerical factor (k) enters; thus,

$$C = k\frac{E}{R}$$

What this constant factor k is will depend on what units we employ. Now, by referring back to § 41, it will be seen that by our definition of the practical unit, R is unity when C and E are unity, or $1 = k\frac{1}{1}$; hence k is one and may be omitted; thus,

$$C = \frac{E}{R}$$

Our system of units was, in fact, chosen with a view to having this so.

46. Ohm's Law and Resistance.—The idea of electrical resistance is frictional opposition to the flow of electricity, just as ordinary friction between two bodies means opposition to the movement of one over the other. Now, we may write Ohm's law thus :—

$$R = \frac{E}{C}$$

So that resistance is the ratio of electro-motive force to current produced. The real meaning of Ohm's law is that this ratio is, for a given conductor in a given physical condition, a constant; so that our measure of the resistance of a conductor is the constant ratio of the electromotive force producing a current in it to the current so produced.

The resistance of a conductor depends on the dimensions of the conductor, as follows: If the length of the conductor be l, the area of its cross-section a, then its resistance is

$$R = k\frac{l}{a},$$

where k is a constant independent of the dimensions of the wire. If we take a piece of the conductor of unit length and unit cross-section, $l = 1$ and $a = 1$, and then $R = k$; or, k is the resistance of a piece of the conductor of unit length and unit cross-sectional area, and is called the specific resistance of the substance of which the conductor consists.

Conductivity.—The conductivity, or conducting power of a conductor, will be greater, of course, the less its resistance. We may, then, take it as the reciprocal of the resistance, or $= \frac{1}{R}$, and then from Ohm's law it will mean the ratio of the current in the conductor to the electro-motive force that produces it.

46. CONDITIONS ON WHICH RESISTANCE DEPENDS.—*The Material of the Conductor.*—Some substances are naturally good conductors, and

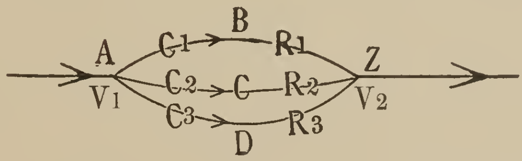


FIG. 16.

others naturally poor. Among metals, copper is one of the best conductors, and hence it is the most commonly employed. The conductivity of silver stands higher than that of copper, but its cost prevents its use. After copper come platinum, iron, lead, mercury, German silver, in the order named. It is interesting to note that this is also the order of the metals as regards conducting power for heat. In fact, the ratio of the conductivities for heat and electricity is nearly constant not only for metals, but also for alloys.

Physical State.—In all ordinary metal conductors the conductivity decreases as the *temperature* rises. The increase of specific resistance per unit rise of temperature is called the *temperature coefficient* of the substance. It is nearly the same for all pure metals except thallium and iron, being .0037647 per degree centigrade. Again, metals become worse conductors on having their *hardness* increased. The resistance of steel is increased by tempering, while hard-drawn copper wire is a worse conductor than annealed copper. Finally the resistance of a wire is changed by *strain;* stretching increases the resistance of the wire, while longitudinal compression decreases its resistance.

47. CONDUCTION OF LIQUIDS.—Liquids are divided into two classes: (1) those which conduct without decomposition, as liquefied metals and

some compounds; (2) those which are decomposed by the passage of the current, and are called electrolytes, the process of their decomposition being called *electrolysis*. We shall take electrolysis up more fully a little later. But we anticipate enough to say that Ohm's law holds for electrolytes also (§ 62).

48. Resistance of a Multiple Arc.—A multiple arc is the technical name applied to an arrangement of wires in which several wires connect two points so that several channels are open to the flow of electricity. (Fig. 16.) We are supposed to know the separate resistances,—say, R_1, R_2, R_3,—and we wish to know what the effective resistance of the combination will be. If the potential at A and Z be V_1 and V_2, then the difference, $V_1 - V_2$, will be the electro-motive force, E, acting along each wire; and then, by Ohm's law,

$$C_1 = \frac{E}{R_1},\ C_2 = \frac{E}{R_2},\ \text{and}\ C_3 = \frac{E}{R_3}$$

Suppose these wires removed and replaced by a single wire of resistance, R, such that the current still remains the same, or $C = C_1 + C_2 + C_3$; then, since Ohm's law would still hold for this conductor,

$$C = \frac{E}{R}$$

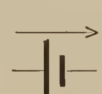
$$\text{Hence,}\ \frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

This means that the conductivity of the combination (or the *reduced* conductivity of the multiple arc) is simply the sum of the conductivities of the separate conductors, and R can be readily calculated.

As a simple example, let us find the resistance of a wire that would just replace three in multiple arc, whose resistances are 1, 2, and 3 ohms, respectively:—

$$\frac{1}{R} = \frac{1}{1} + \frac{1}{2} + \frac{1}{3} = \frac{6+3+2}{6} = \frac{11}{6} \therefore R = \frac{6}{11}\ \text{ohm.}$$

49. Arrangement of a Number of Cells for Greatest Current.—For the purpose of what follows, we shall employ the simple conventional sign,



to represent a cell, the large line representing the zinc, or positive plate, and the small one the copper, or negative plate, so that the current flows in the direction of the arrow. We must also define the terms *external* and *internal resistance.* That part of the resistance of a circuit which is constituted by the cells used is called the internal resistance, and the remainder, due to the parts of the circuit outside the cells, is called the external resistance.

There are two separate ways in which we can arrange a battery of cells, and a third way that is a combination of the two.

(*a*) *In series*, *i.e.*, the copper of each being connected to the zinc of the next, thus :—

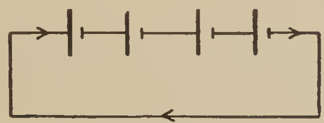


FIG. 17.

(*b*) *Abreast* or in multiple, *i.e.*, all the coppers being joined together and all the zincs together, thus :—

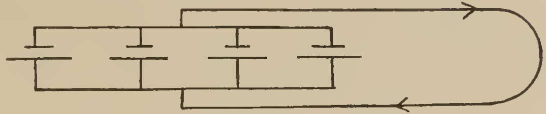


FIG. 18.

Comparison of the Two.—Let the electro-motive force of each cell be E. Then it is easily seen that in the arrangement in series the second zinc plate is at the same potential as the first copper plate, and therefore E in potential below the first zinc plate. The second copper plate is, therefore, 2E below the first zinc plate. The last copper plate is nE in potential below the first zinc plate; hence the electro-motive force of the combination is nE. But if the resistance of each cell be R, then the resistance of the combination is nR. If, then, the internal resistance be much larger than the external, the whole resistance of the circuit will be n times what it would have been with only a single cell, while the electro-motive force will have been increased n times also; so that the n cells will not give a much better current than one cell.

If, on the other hand, the external resistance be very large compared with that of a single cell, the arrangement in series will be advantageous, since it greatly increases the electro-motive force in the circuit without adding appreciably to the total resistance.

Turning now to the arrangement abreast,—since all the positive plates are at the same potential and all the negative plates at the same potential, the electro-motive force of the whole arrangement is simply that of a single cell. But since n channels are now afforded for the flow of the current through the battery part of the circuit, the resistance of the combination will only be one nth that of a single cell, or R/n. If, now, R be small compared with the external resistance, we shall not have reduced the whole resistance of the circuit much by dividing R by n, and so the arrangement will hardly be more effective than a single cell would be. But if the internal be the chief portion of the resistance, then by dividing it by n we shall have greatly reduced the total resistance.

Hence, a general rule: If the resistance of a single cell is less than the external resistance, arrange your cells in series; if greater, arrange your cells abreast.

(*c*) But there is a third way of arranging the cells. Suppose, *e.g.*, we have 24 cells, then we can divide them into six groups of four each. Each group of four we can arrange in series so as to act as a single cell, of an electro-motive force 4E and an internal resistance 4R. Then these six groups can be arranged abreast, so that the electro-motive force is still 4E, but the internal resistance of the combination $\frac{4R}{6}$; and then, if the external resistance be r, by Ohm's law we shall have a current of

$$\frac{4E}{r + \frac{4R}{6}} = \frac{24E}{6r + 4R}$$

But we could also have divided this into eight groups of three cells each, and then the current would have been

$$\frac{3E}{r + \frac{3R}{8}} = \frac{24E}{8r + 3R}$$

or four groups of six each, and which of these will give the greatest current will again depend on the relative magnitude of r and R; and if the matter is investigated mathematically, we shall arrive at the following rule for the arrangement giving greatest current: Divide the cells into a number of groups, such that the ratio of the number of groups to the number in each group shall be as nearly as possible equal to the ratio of the resistance of a single cell to the total external resistance. Then arrange each group in series (*a*), and put all the groups abreast (*b*).

Wheatstone's Bridge Measurement.

50. Standards of Resistance and Electro-motive Force.—We proceed now to indicate briefly the exact methods employed in measuring resistance and electro-motive force. Before doing so, we must describe the standards used in measuring resistance.

Resistance.—At a given temperature a given wire has a perfectly definite electrical resistance. Accordingly, if we take a bobbin of wire (German silver is usually employed), the coils being covered with silk or some insulator, so that there is no "short-circuiting," or passage of current from coil to coil in contact (the current must pass longitudinally from end to end of the wire), we can use such a bobbin as a standard for comparing electrical resistance; and further, if we take a series of such, graduated to ohms and parts of an ohm, in the same way as weights for a fine balance are graduated in grammes and parts of a gramme, such a series of graduated resistances will enable us by comparison to measure any unknown resistance. Such a series, arranged with their terminals

on the cover of a box, in which the bobbins hang for protection, is called a resistance-box. The alloy German silver, which consists of nickel and copper, is usually employed, because it has a low temperature coefficient, *i.e.*, suffers but small proportionate increase of resistance on increase of temperature.

Electro-motive Force.—Any very constant cell can be employed for comparing electro-motive forces. The one usually employed is a cell invented by Latimer Clark, and having a very constant electro-motive force. The poles are amalgamated zinc and mercury, and the liquids are sulphate of zinc and a paste of sulphate of mercury. Its electro-motive force is 1.457 V.

51. WHEATSTONE'S BRIDGE.—Take a multiple arc of two branches, A C B and A D B, and pass a current from a battery through it. The potential at A is the same for both branches, also the potential at B. It falls off

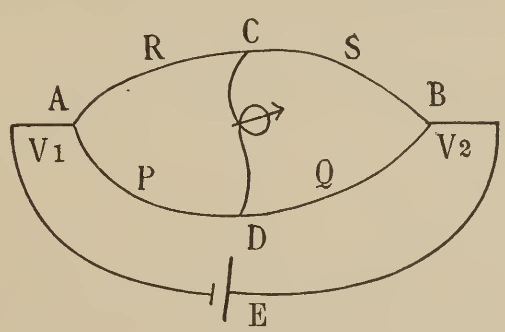


FIG. 19.

along A C B, and also along A D B. Now by Ohm's law, since the current in all parts of A C B is the same, the fall of potential in any part of A C B is proportional to the resistance of that part. Hence, if we take two points, C and D, at the same potential, then C must divide the resistance of A C B in the same proportion as D divides that of A D B. Calling the resistances of the parts P Q and R S, we have

$$\frac{R}{S} = \frac{P}{Q} \text{ and } R = \frac{P}{Q} S;$$

and since C and D are at the same potential, if we join them by a galvanometer it will indicate no current. Hence, if we adjust the resistances till there is no current given by the galvanometer, and let P, Q, and S be known resistances given by a resistance box, we have R, which we suppose to be an unknown resistance, to be measured. This method of arranging so that the galvanometer shows no current, and thus deducing the unknown quantity, is called a *null* method. It is the ordinary way of measuring electrical resistances.

When in any such net-work two branches are so related (as the

battery and galvanometer branches are in this net-work) that a change in one (such as suddenly "throwing in" the battery) does not affect the current in the other, they are said to be conjugate branches.

Galvanometer Resistance.—If we wish to know the resistance of a galvanometer we may simply put it in the unknown arm, R, in which case we shall have to employ a second galvanometer, C D. But this second galvanometer in C D is unnecessary, for all we need to see is that no current flows through C D,—*i.e.*, no change in the existing currents is caused by connecting C and D, and this can be equally well seen by watching the galvanometer in A C while we make and break, by means of a key, the continuity of the simple wire joining C and D. This is Thomson's method of finding a galvanometer resistance.

Battery Resistance.—Again, to find the resistance of a battery, we may put it in A C and proceed as at first, with a galvanometer in C D and battery in A E B. But, now, the battery in A E B is unnecessary, for the battery introduced in A C keeps up currents in the net-work and the battery in A E B can be simply replaced by a key; and if we adjust the resistances in the arms P, Q, and S till no effect on the galvanometer in C D is produced by making and breaking with the key in A E B, then, as before, we have

$$R = \frac{P}{Q} S.$$

General Rule for Battery or Galvanometer Resistance.—Starting with the original arrangement, to modify it, in order to find the resistance of a galvanometer or battery, all we have to do is to put the battery or galvanometer in the unknown arm, R, and replace the battery or galvanometer of the net-work by a key, and then seek a *null* adjustment, whereupon we have

$$R = \frac{P}{Q} S.$$

52. Comparison of Electro-motive Forces.—The method we shall employ is what is known as du Bois-Reymond's compensation method: Let e be the electro-motive force of a battery to be measured, and E that

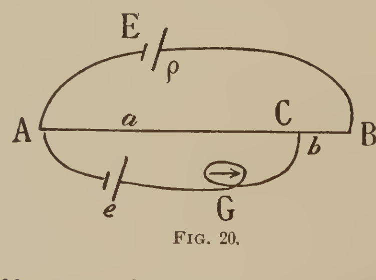


Fig. 20.

of a standard cell of known resistance, ρ. Join the poles of E by a long, thin wire lying beside a graduated scale, by means of which we can read

the lengths of parts of the wire. Also, join e in series with a galvanometer to A and a variable point, C, in A B. E will tend to produce a current in A G C in the direction from A to C through G. On the other hand, e will tend to produce a current in the opposite direction. Now, by adjusting C along A B so as to increase or decrease the resistance, a, of A C, we can send more or less of the current from E through A G C, and so can adjust till the currents produced by E and e in A G C just neutralize one another, which will be indicated by the galvanometer, G, showing no deflection.

The reason no current goes through G is that, although the battery E produces a slope of potential along A G C, the battery e produces an equal and opposite one. The slope produced by E, or the difference of potential between A and C, is the same part of the whole electro-motive force of E that the resistance of A C—*i.e.*, a—is of the whole resistance of the circuit E A C B, *i.e.*, $\rho + a + b$. Putting these two statements together, we see that

$$e : E :: a : \rho + a + b.$$

Now, a, ρ, and b are all known or measurable resistances; hence the ratio e/E can be found.

Electrical Energy and Chemical Energy; Electrolysis.

53. Conduction in Liquids.—Unlike as electrical energy and chemical energy may be at first sight, still, they are both forms of energy, and, therefore, capalbe of being changed into each other. Chemical energy we know consists in the energy of certain attractions and repulsions. Electrical energy consists in the energy of something in motion. The currents we have been treating of so far were examples of the change of chemical energy in Volta's cell into energy of a current of electricity. We proceed now to consider the converse process,—the change of the energy of an electrical current into chemical energy. The chief example is what occurs in the passage of electricity through liquids.

As regards the conduction of electricity, liquids may be divided into three classes:—

(1) *Those that Conduct Like Solids.*—This class contains all metals in the liquid state, whether like mercury at ordinary temperatures or like iron fused at a high temperature.

(2) *Those that Do Not Conduct at all.*—To this class belong pure water, pure hydrochloric acid, and generally all pure liquefied hydrogen acids (except HCN), fluid chlorine, bromine and iodine, oils and resins (gases and vapors are also non-conductors; any decomposition in them is due to convective discharge).

(3) *Those that Conduct, but with Chemical Decomposition.*—To this class belong dilute acids and most simple binary compounds, *i.e.*, compounds of two elements and compounds derived from them by double decompositions.

54. Typical Case of Conduction with Decomposition.—The meaning of electrolysis has already been explained. By derivation, it means the electrical decomposition of chemical compounds. Faraday was the

inventor of this and most of the following terms. A compound so decomposed is called an *electrolyte.*

To explain the terminology, we shall take a typical case. In a vessel containing zinc chloride ($ZnCl_2$) suspend two platinum strips connected with a battery. It will be found that zinc appears at one strip and chlorine at the other. These strips are called electrodes, and the cell so equipped is called a voltameter. The zinc is precipitated, and the chlorine forms platinic chloride with the platinum. The decomposing current enters at the strip connected with the copper or negative plate of the battery, and this strip is called the *anode.* The current leaves at the strip connected with the zinc or positive plate of the battery, and this strip is called the *cathode.* These terms are taken from the analogy of the motion of the sun, the anode being the place where the current "rises" (*ana hodos*, or way up), and the cathode where it sets (*kata hodos*, way down).

Thus it will be seen that the zinc travels with the current to the cathode, and the chlorine against the current to the anode. These components are accordingly called *ions*, from a Greek root meaning to go: the ion that appears at the anode being called the *anion*, and that which appears at the cathode the *cation.*

The positive current goes from the zinc to the copper and carries zinc with it; hence, the zinc, or cation generally, is called electro-positive. The negative current goes from the copper to the zinc and carries chlorine with it; hence, the chlorine, or anion generally, is called electro-negative.

Any reactions—following ordinary chemical laws—between the primary products of electrolytic decomposition, the electrolyte, and the electrodes are called *secondary reactions.*

55. Comparison of Simple Conductors and Electrolytes.—*Contrast of Resistance.*—The resistances of electrolytic conductors are very high compared with those of simple metallic conductors,—*e.g.*, pure H_2SO_4 has seventy million times as great a specific resistance as pure copper.

Contrast of Temperature Effects.—The resistance of metals is increased by rise of temperature,—of pure copper about $\frac{2}{5}$ per cent. per degree centigrade. The resistance of electrolytes is decreased by rise of temperature,—of pure H_2SO_4 about 4 per cent. per degree centigrade.

Faraday's Law of Conductors.—Faraday established a law, to which there seems to be *no* exception, viz., that all substances which in the solid state are very bad conductors, but conduct on being melted, are electrolytes, *i.e.*, conduct with decomposition.

56. Faraday's Law of Electrolysis.—Faraday discovered that the resistance to the separation of an element from a compound by an electric current is the same, no matter what the compound, and depends merely on the element. Hence the law of electrolysis: The amount of ion that appears at an electrode in a second is equal to the strength of the

current (supposed constant during a second) multiplied by a constant called the *electro-chemical equivalent* of the ion. For example, if the electro-magnetic unit of an electrical current (the ampère) flow per unit of time (a second), it will liberate .000010352 gramme of hydrogen, which therefore is the electro-chemical equivalent of hydrogen. We can readily make out a relation between electro-chemical and chemical equivalents; for if, in the above case, a certain quantity of H is liberated at the cathode, the quantity of Cl combined with it (supposing the electrolyte to be HCl) must appear at the anode. Now, every atom of H has combined with it one atom of Cl. Hence the quantity of Cl liberated must have weighed more than that of H in the proportion of the atomic weight of Cl to that of H, *i.e.*, in the ratio of 35.5 to 1. Again, in the above typical case, the electrolysis of $ZnCl_2$, since in each molecule there are two atoms of Cl to one of Zn (*i.e.*, one of Zn is chemically equivalent to two of Cl; or, the "valency" of Zn is 2), only half as many atoms of Zn will be set free by electrolysis as of Cl; and since the atomic weights are of Zn 65 and of Cl 35.5, the weights liberated will be as $\frac{65}{2}$ to 35.5. Hence the electro-chemical equivalents of substances are proportional to their atomic weights divided by their "valencies."

57. Polarization and Transition Resistance.—The decomposition of the electrolyte, with the consequent deposition of the products of decomposition on the electrodes, produces two effects.

Polarization.—In the first place, the change in the nature of the surfaces produced by the deposition means an alteration in the nature of the contacts, and, therefore, a change in the electro-motive force of the circuit. This will be true whether the products of decomposition are simply deposited on the plates or combine with them chemically. The new electro-motive force thus introduced is usually opposed to the main electro-motive force, and is, consequently, called a "back" electro-motive force, or electro-motive force of polarization. Its presence is shown by suddenly throwing the voltameter out of the main circuit and connecting it with a galvanometer. It will then be found to act as a cell itself, though its electro-motive force will, as a usual thing, very rapidly fall away. The "back" electro-motive force is caused by the tendency of the dissociated atoms to re-unite, and thus is a measure of the attraction of these atoms, or of their "chemical affinity."

Minimum Electro-motive Force Required for Electrolysis.—It is evident that the initial electro-motive force required to start electrolysis must exceed the "back" electro-motive force that would be produced by the process. Hence we have usually a lower limit to the electro-motive force that will start electrolysis. For instance, a single Smee's cell, no matter how large and close together its plates, will not electrolyze acidulated water, for the back electro-motive force so produced is 1.47 V, which is greater than the electro-motive force of a Smee cell. The current will cease before it has produced any appreciable effects.

58. Secondary Actions.—These may be classified as follows :—

(*1*) *Appearance of Ions in Abnormal Molecular States.*—The most important example of this is the production of ozone along with oxygen in the water voltameter. The amount produced is never large, but can be readily recognized in the ordinary way by making it replace the iodine in potassium iodide, setting free the iodine to act on starch. The amount produced is largest when chromic and permanganic acids are electrolyzed.

(*2*) *Resolution of Compound Ions.*—As an example, take the electrolysis of oxyacids, *e.g.*, H_2SO_4. Here the ions are H and SO_4. The latter, which has been named Oxysulphion, immediately breaks up into O and SO_3.

(*3*) *Reaction of Ions on Electrodes.*—At the cathode, where the metals are set free, the usual result is the formation of an alloy of the metal of the cathode and the metallic ion. An example can be readily obtained by electrolyzing copper sulphate with platinum electrodes. At the cathode an alloy of copper and platinum is formed which penetrates a considerable distance into the platinum. This union of the ions with the electrodes takes place the more readily because the ions are in the *nascent* state (§ 4). The oxygen liberated at the anode frequently unites with the anode, even carbon becoming then oxidized to CO and CO_2.

(*4*) *Reaction of Ions on Fluids at Electrodes.*—Such nearly always occurs unless the ions act on the electrodes themselves. Take, as an example, the electrolysis of sodic sulphate or Glauber's salts,—Na_2SO_4. The immediate effect of electrolysis is to break it up, thus :—

$$Na_2SO_4 = Na_2 + SO_4.$$

The Na_2 appears at the cathode and reacts on the water there, thus :—

$$Na_2 + 2H_2O = 2NaHO + H_2.$$

The SO_4 breaks up into O and SO_3. The former appears at the anode and the latter unites with water, thus :—

$$SO_3 + H_2O = H_2SO_4.$$

The presence of the H_2SO_4 and NaHO can be readily indicated by mixing some extract of red cabbage with the solution. If necessary, a drop or two of acid is added till the whole is a dull-purple color. Then the presence of the acid at the anode is indicated by its turning the solution red, and that of the alkali at the cathode by its turning the solution green.

59. The Electro-chemical Series.—The preceding may have suggested that an element was always an anion or always a cation ; but this is not so. The terms anion and cation are merely relative. It is found that all substances can be arranged in a series, such that any substance is a cation when combined with any lower in the series and an anion to any higher ; the beginning of the list being accordingly most electro-positive

and the end most electro-negative. At the head of the list, or most strongly electro-positive, stand K, Na, Li, Ba, etc.; at the end I, Br, Cl, Fl, N, Se, S, O (for full list see *Encyclopædia Britannica*, "Electrolysis"). Thus the same substance may be sometimes an anion and sometimes a cation, according to the position of its companion ion in the list.

60. Electric Osmosis, or Cataphoresis.—In ordinary osmosis (§ 6) the liquids must be different. But even with the same liquid on both sides of the porous partition the passage of an electric current from one side to another will cause more liquid to diffuse in one direction than the other, so that it will rise to a greater height on one side than on the other. This is called electric osmosis, or cataphoresis. The latter name is derived from the fact that the liquid is carried down (*cata*, down; *pherein*, to bear) with the current, *i.e.*, more liquid passes by diffusion through the partition in the direction of the current than in the opposite direction. The process may be shown by using a weak solution of starch and a weak solution of iodine separated by a porous partition. The current, on passing from the iodine to the starch, will carry some of the former with it, thus coloring the starch by chemical reaction with the iodine. This

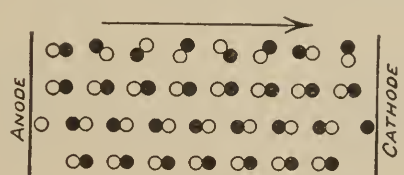


Fig. 21.

● an atom of hydrogen; ○ an atom of chlorine; ——> direction of current.

process plays an important part in medical applications of the electric current, or the process known as *cataphoric medication.*

61. The Mechanism of Electrolysis—Grotthüss and Clausius.—This process of electrolytic conduction is at first sight somewhat parodoxical. For, though the current passes from electrode to electrode, and must, therefore, pass through the liquid, yet the chemical evidence of the current, viz., decomposition, only appears at the electrode. Does, then, the current produce no decomposition in the body of the liquid?

Grotthüss's Theory.—The answer given by Grotthüss is that there is decomposition everywhere, but, whereas there is immediate recomposition in the body of the liquid, there is no such recomposition at the electrode, and so the components appear there. This theory may be represented thus (Fig. 21): In the electrolysis of HCl the first thing that happens is a wheeling of all the molecules into line, all the H atoms pointing toward the cathode and all the Cl atoms toward the anode. Then each molecule ruptures and each atom turns to the dissimilar atom on the other side and combines with it, forming new molecules, but leaving free atoms of Cl at the anode and free atoms of H at the cathode. Again the

molecules wheel around into position and again the process is repeated, and so on.

This theory will evidently explain (1) the appearance of the products of decomposition at the electrodes and (2) Faraday's law as regards a single electrolyte. It does not, however, explain (3) the transference of the electricity nor (4) why the same amount of an ion should be separated from different electrolytes by the same current.

Berzelius's Extension of the Theory.—The extension made by Berzelius is that on the union of H and Cl to form HCl electrical distribution takes place in a similar way to that of magnetism in a bar magnet, H becoming the positive and Cl the negative pole. When the anode has become sufficiently highly charged with positive electricity its attraction on Cl becomes greater than that of the H atom, and so the HCl molecule is decomposed. Helmholtz further suggested that each atom carries with it a certain definite charge. If the atoms on decomposition cling to their electrical charges these latter cannot be passed around to the other plate, and may accumulate and partly neutralize the attraction of that plate for the ions. This gives rise to an electro-motive force of polarization.

62. Electrolytic Resistance and Ohm's Law.—The measurement of the resistance of an electrolyte is a matter of considerable difficulty, chiefly owing to the complications introduced by the polarization electromotive force, which, so far as weakening the current is concerned, is equivalent to an added resistance. The means resorted to have been these :—

(1) Horsford used a voltameter in which the electrodes were at measurable distances, which could be altered. The plates were brought nearer together by a known amount, and the current kept constant by inserting a known resistance from a resistance-box. The current being constant, it was assumed the polarization was, and so the added resistance was the resistance of a thickness of the electrolyte equal to the distance by which the plates were brought nearer.

(2) Beetz employed the principle that carefully amalgamated zinc plates in a neutral solution of zinc sulphate are not polarizable, and so measured the resistance of zinc sulphate.

(3) Paalzow inclosed the electrolyte in a siphon which dipped into vessels of porous earthenware filled with the electrolyte. Those porous vessels were immersed in beakers filled with zinc sulphate, at the bottoms of which were large amalgamated zinc discs forming the electrodes. Thus there would be no polarization except possibly at the surface of contact of the liquids, and that would be small.

(4) Kohlrousch and Nippoldt used rapidly alternating currents, and so the ions would recombine as fast as separated and no polarization would ensue.

By all these means Ohm's law has been fully proven to hold true for liquids as well as for solids.

63. Secondary or Storage Cells.—We have seen that, in general, the passage of a current through a voltameter alters the electrodes by secondary actions between the ions and the electrodes. Thus, if before the passage of a current the electrodes were quite similar in substance, after the passage they are dissimilar; and therefore the voltameter has become

a voltaic cell and can be detached and used as such until, by the reverse current started, the work done on the electrodes by the original current is undone, or the electrodes are discharged. A cell so constructed is called a secondary cell, because it is not of itself primarily a generator of a current, but only subsequent to the passage of a current through it. Secondary cells are also called storage cells, but it is not meant thereby that they store up electricity. What is meant is that they store up energy, namely, in the chemical form, and that this energy can be reproduced as the energy of an electric current. They are also frequently called accumulators. Any voltameter in which similar electrodes are rendered dissimilar by the passage of a current becomes a secondary cell, but only a few have been so constructed as to maintain a current for any considerable length of time.

Grove's Gas-Battery.—If acidulated water be electrolyzed in a closed voltameter with long electrodes of platinum, so that the gases are retained surrounding the electrodes, after the decomposition has proceeded for some time the voltameter has become a charged secondary cell, and can

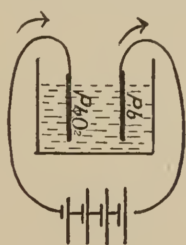


FIG. 22.

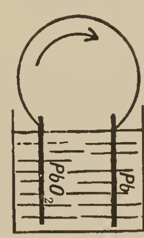


FIG. 23.

be used as such until all the decomposed gases have disappeared by decomposition. Or the gases may be otherwise prepared and then introduced.

Planté's Secondary Cell.—In Planté's secondary cell the electrodes are lead plates immersed in dilute H_2SO_4. In its original form the preparation of the plates, or the "formation" of the cell, as it was called, was a troublesome process. First, a current was passed through it till the surface of the anode was oxidized into PbO_2 (Fig. 22). Then the current was reversed, whereupon the PbO_2 was reduced, leaving that surface covered with "spongy" lead, and covering the surface of the other plate with PbO_2. The current was again reversed, and so on for weeks, until the lead surfaces had been acted on and rendered "spongy" to some depth. The plate that last served as anode remained deeply coated with PbO_2.

If the cell be now used to generate a current, this current will be in the direction from the peroxidized plate to the plain lead plate (Fig. 23). The chemical changes will consist in the reduction of the PbO_2 to PbO, and the oxidation of the Pb plate to PbO; so that the two plates become

similar. When this state is attained the cell is "run down." It must then be "re-charged," which consists in sending a reverse current so as to again peroxidize one plate and reduce the other to spongy lead, and thus the cell is again charged. (In this simple account we have neglected the presence and action of $PbSO_4$ on the plate. Chemically it is negligible, but mechanically it seems to serve the important purpose of separating the PbO_2 from the Pb below it, and so preventing the PbO_2 from being reduced by mere "local action" between the PbO_2 and the plate on which it is, and thus giving no current.)

Fauré's Modification of Planté's Cell.—There is a great waste of energy in the process of "formation" of Planté's cell. To avoid this, Fauré coated the plate to begin with with minium, or red lead,—Pb_2O_3, or $PbO.PbO_2$. Then, on charging by passing a current we get H_2 set free at the cathode and O at the anode, and the reactions that take place are :—

$$\text{At cathode, } Pb_2O_3 + 3H_2 = 3H_2O + \underline{2Pb}.$$

$$\text{At anode, } 3Pb_2O_3 + 3O = \underline{6PbO_2}.$$

Thus we shall have one plate peroxidized and the other spongy lead, and the cell is charged ready for use.

The chief difficulty in this cell is to make the minium adhere to the plates. For this purpose the plates are gridironed and the minium packed in the interstices in the lead, or some other similar device is resorted to.

The electro-motive force of such a cell is over two volts; so that to charge a single cell with primary batteries at least three Bunsen cells are required. If all the storage batteries during charging are connected abreast, any number can be charged by a few Bunsen elements (requiring, of course, proportionately longer time), and then they can be connected in series, and so a much higher electro-motive force obtained than from the charging battery.

Electrical Energy and Heat Energy.

64. Their Interchangeability.—Heat, being a form of energy, is interchangeable with other forms of energy, and among them with electrical energy. Of the change of electrical energy into heat energy we have an example in every current of electricity. For heat is the form of energy generated whenever work is done against frictional resistance; and as electrical resistance is of the nature of friction, and all conductors offer some resistance to electric currents, heat is generated by every current. We shall first discuss the change of electrical energy into heat energy, and then the change of heat energy into electrical energy. The currents obtained by this latter process are usually called thermo-electric currents.

65. Development of Heat in a Circuit.—A current of electricity generated by a voltaic cell is capable of doing work, such as turning an electric motor. But if the current be merely passed through a wire doing no work, it must produce heat, since the same amount of chemical energy is used up in the cell, and it must be reproduced in some other form of energy.

It can be shown without difficulty that the heat so produced in a wire varies as the square of the current and the first-power of the resistance conjointly. For by definition the difference of potential between the ends is the work done in carrying a unit of positive electricity from one end to the other. Hence, if the difference of potential or electro-motive force be E and the current be C, then, since C is the number of units of electricity that pass in unit time, the work done in unit time is $W = EC$; and by Ohm's law $C = \frac{E}{R}$, or $E = CR$; hence, $W = C^2R$. If C and R be in C. G. S. units, W will be the number of units of heat energy produced per second.

Thus the heat energy produced depends only on the current and resistance. Hence, to avoid loss of energy by heating the conductors, a small current and low resistance is to be used. This is the secret of electrical transmission of power. The power is transmitted as an electrical current of small current-strength, though high electro-motive force, and then when it is to be used it is transformed into a larger current of lower electro-motive force.

Where heat is to be developed high resistance is used. In electro-cautery the surgeon wishes to burn off a growth by a heated wire, and so he uses not silver, which, for one thing, would have too small a resistance, but platinum, which has a higher resistance.

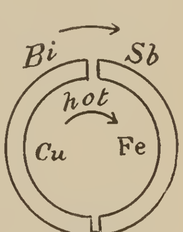


Fig. 24.

Again, incandescent lighting depends on the heating to incandescence of a carbon filament of high resistance. In the arc-lamp the resistance is in the carbon vapor between the carbon points, and the light is produced by this incandescent vapor, but chiefly by the heated ends of the carbon rods.

66. Production of Electricity from Heat.—We now proceed to the converse process,—the transformation of thermal energy directly into electrical energy. The first to discover the possibility of this was Seebeck. He found that in a circuit of only two metals a current can be produced by simply heating one junction to a higher temperature than the other. This can be very readily shown by winding the ends of a copper and an iron wire together and then heating that junction, while the other ends are connected to a galvanometer. A current will be found to flow in the direction from copper to iron through the hot junction. The same thing can be shown still more strikingly by using bismuth and antimony, when the current will be found to flow from

bismuth to antimony through the hot junction. Similar phenomena will be produced by using any pair of metals.

Thermo-Electric Power.—To render our ideas more definite, in describing the current or electro-motive force produced by any such couple of metals, we must specify the difference of the temperatures at which the junctions are. Moreover, the electro-motive force may depend not only on the *difference* of temperature of the junctions, but also on their actual temperatures. Hence, we define the *thermo-electric power* of a couple at a specified temperature as the electro-motive force produced by keeping one junction $\frac{1}{2}°$ C. above and the other $\frac{1}{2}°$ C. below that temperature. With this definition it will be found that the thermo-electric power is different at different temperatures (§ 69).

67. Thermopiles and Thermo-Electric Batteries.—With a thermo-electric couple, then, we have a means of generating electric current directly from heat. But the electro-motive force of such a current is very low,—for a Cu-Fe couple with one junction 1° C. above the rest of the circuit it is only .0000137 volts, and for a Bi-Sb couple it is .000117 volts.

But we can obtain a much greater electro-motive force in the following way: Instead of taking a single piece of Bi and a single piece

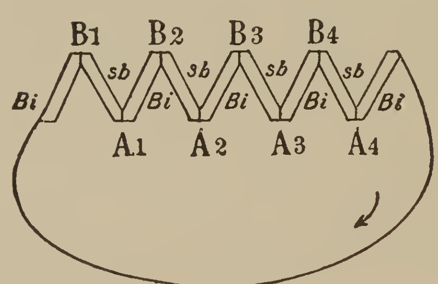


Fig. 25.

of Sb, take a number of pieces and connect them up alternately as in the diagram. Then, if a B junction be heated, it is evident, by the rule above, the current will be in the direction of the arrow; but if any A junction were heated, the current would be in the opposite direction. Hence, to get a greatly-increased electro-motive force, we heat all the B junctions, keeping all the A junctions at the ordinary temperature. Thus, by multiplying the number of junctions, we can multiply the thermo-electro-motive force to any desired extent.

Such thermo-electric multipliers have been made for different purposes in two different forms. One form—the *thermopile*—is used as a very sensitive detector of heat. It consists of a circuit such as described, except that the strips are packed together, with strips of paper or gutta-percha between them for insulation, into a box, so that all the A junc-

tions are exposed at one end and all the B junctions at the other. When either end is exposed to a source of heat, a current will be indicated by a sensitive galvanometer in circuit with the thermopile.

The Thermo-Electric Battery.—The above arrangement can also be employed to generate currents. For this purpose the cold junctions must be kept at a low temperature,—*e.g.*, by immersion in ice; and the hot junctions heated to a high temperature,—*e.g.*, by immersion in boiling water, or by heating by gas-burners or some similar means. Such batteries have been made by Pouillet, Becquerel, Clamond, and others, and can be used for such purposes, as electro-cautery and telegraphy, as do not need a very considerable electro-motive force, but only a large current.

68. Heating or Cooling of Junction by Passage of Current.—We have seen that in any part of a conductor heat is generated by the passage of a current. Such heat is due simply to the frictional resistance the conductor offers to the passage of a current. We have also seen that, conversely, if one junction of a circuit of two different metals be heated, a current is produced by the absorption of heat. But the former is not quite the converse of the latter. The proper converse of this would be if heat could be produced at the junction by the passage of a current. This can really be done, as was discovered by Peltier. His discovery was this: Pass a current through a junction of two different metals; then heat will be disengaged if the current be in opposition to the direction in which a current would be produced by heating the junction, and heat will be absorbed if the current be in the direction of the current that would be produced by heating the junction.

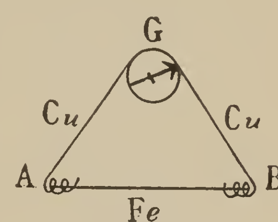


Fig. 26.

For example, if a current be passed through a Bi-Sb junction from Sb to Bi, the junction will be heated by disengagement of heat; if the current be passed in the opposite direction, from Bi to Sb, the junction will be cooled by absorption of heat.

There will be no difficulty in remembering these facts if it be remembered that, both in the Seebeck effect and in the Peltier effect, a current from Bi to Sb is always attended with absorption of heat.

69. Neutral Point and Reversal.—If we connect two Cu wires to a galvanometer and also wind their free ends around an iron wire, A B (Fig. 26), we can verify the following phenomena discovered by Cumming. Heating the junction, B, a current will go in the direction $\overrightarrow{BA}$, as shown by the galvanometer. It will increase heat at a decreasing rate: when B is at 260° C. it will become steady, and then will decrease until at 500° C. (supposing A to be constant at 20° C.) it will become zero, and then will turn in the opposite direction.

Now, it will be noticed that the temperature of reversal is as much above 260° C. as the temperature of A is below it. This would be true no matter what the temperature of A. Thus,

A being at 20° (= 260 − 240°),	reversal occurs at	500° (= 260 + 240°).
" " " 100° (= 260 − 160°),	" "	" 420° (= 260 + 160°).
" " " 250° (= 260 − 10°),	" "	" 270° (= 260 + 10°).
" " " 259½° (= 260 − ½°),	" "	" 260½° (= 260 + ½°).

Now, by remembering the definition of thermo-electric power at a certain temperature as the electro-motive force when one junction is half a degree above and the other half a degree below that temperature, the last result in the table is readily interpreted as meaning that at 260 degrees the thermo-electric power of a Cu-Fe couple is zero, or the metals are *neutral* to one another. Hence, 260 degrees is called the *neutral point* for an Fe-Cu couple.

Similar results hold true for all other couples. Each couple has its neutral point or point of zero thermo-electric power, and when one junction is a certain number of degrees below the neutral point reversal will occur when the other is an equal number of degrees above it.

70. Thomson Effect.—From the above results Sir William Thomson reasoned as follows: When one junction is kept at the neutral temperature and the other at a lower temperature, there is undoubtedly a current. viz., from Cu to Fe through the hotter junction. Now, since in a junction at the neutral temperature the metals are neutral to each other,—*i.e.*, show no difference of electro-motive force,—the Peltier effect is also at that temperature zero, *i.e.*, no heat would be absorbed or disengaged by passing a current through a junction at that temperature. Hence, there is no heat absorbed at the hot junction. Again, there is not only no heat absorbed but even heat given out at the cold junction. Whence, then, the energy of the current? It must be that heat is taken in along the wires themselves. Now, undoubtedly heat is not taken in when a current passes along a wire all parts of which are at the same temperature; so that the absorption of heat along the wires must be in consequence of their slope of temperature from their hot to their cold ends.

So Thomson was led to the very important conclusion that metal conductors can be divided into two classes. If a conductor belong to the first class a current passing from hot to cold parts along it will absorb heat. Iron belongs to this first class. If the conductor be of metal belonging to the other class, a current on passing from hot to cold will tend to disengage heat. Cu belongs to this second class.

Thus, in Cu the current tends to warm the colder parts and thus equalize the temperature throughout, just as a current of water passing from a hot part of a pipe to a cold part would, and in iron the reverse happens. Using this analogy the whole thing is conclusively summed up in the statement that in Cu electricity has a *positive specific heat* (*i.e.*, gives out heat on cooling), while in Fe it has a *negative specific heat* (*i.e.*, takes in heat on cooling).

Radiant Electrical Energy.

71. Magnetic Field of Current.—We have already (§ 38) touched on the effects produced by a current beyond the conductors themselves in which it flows. We shall now take up briefly this radiation of energy by the electric current. For fuller details of parts bearing direcely on medical applications the reader is referred to the section on faradic current.

The facts on which we founded the statement that the current had a magnetic field were these :—

(1) *Magnet Moved by Current.*—A current in a conductor will deflect a freely-suspended magnet-needle near it.

(2) *Magnet Produced by Current.*—A spiral current will make a magnet of a core of iron inclosed in the spiral.

We shall first take up the converses of these.

72. Momentary Current Produced by Motion of Magnet.—The converse of (1) above would be the generation of a current by the movement of a magnet. This can be shown by inserting a bar magnet into a coil of wire in circuit with a galvanometer and then withdrawing it. It will be found that both at insertion and withdrawal a *momentary* current flashes through the coil, and the directions of these currents are determined as follows: If the bar were not already a magnet, to make it into a magnet with its poles in the direction of the actual magnet would require a current in a definite direction in the coil. Let us call the current that would thus produce the magnet a direct current, and one in the opposite direction a reverse current.

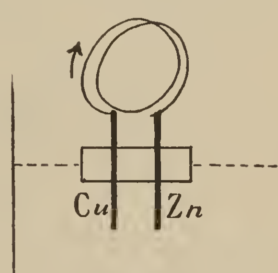


Fig. 27.

Then we may state the above result as follows: The insertion of a magnet into a coil starts a reverse current, and its withdrawal a direct current.

The reader will carefully notice that these currents are only momentary and die down almost immediately, though its own inertia may keep the galvanometer-needle swinging.

73. A Current Equivalent to a Magnet.—The converse of (2) above would be the moving of a circuit carrying a current by a magnet. This can be shown as follows: If a small coil consisting of several turns of copper wire have its ends inserted through a large cork and soldered to strips of copper and zinc and the whole be floated on acidulated water, it is easily shown that the coil is attracted and repelled by a bar magnet just as a small floating magnet would be. (Fig. 27.) It will, in fact, be equivalent to a very short magnet whose axis is perpendicular to the plane of the coil, and whose north and south poles can be found by the

rule that the south to north direction of the axis is related to the direction of the current as the thrust to the twist of a right-handed screw. Such an arrangement is known as De La Rive's floating battery.

Hence, not only will a current make a magnet, but it is itself equivalent to a magnet. The form of the equivalent magnet depends altogether on the form of the current. Taking a long spiral coil of wire it is equivalent to a long bar magnet whose north pole is where the current leaves the magnet if it be a right-handed spiral, and *vice versâ* if left-handed.

74. Momentary Current Produced by Motion of Another Current.—We have now seen that a moving magnet can generate a momentary current in a conductor, and, further, that a current in a circuit is equivalent to a magnet. Hence it seems probable that a current in one moving circuit may generate a current in another circuit.

That this is really so can be readily seen by inserting a spiral carrying a current into another spiral in circuit with a galvanometer and then

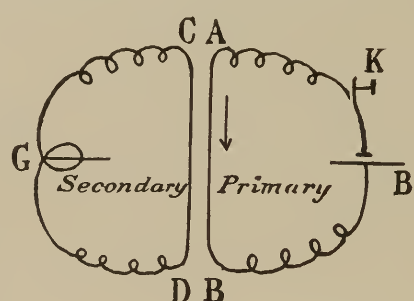


Fig. 28.

withdrawing it. In both cases momentary currents will be observed, whose directions are given by the above rule in § 72.

Such momentary currents are called induced currents.

75. Momentary Current Produced by Varying Another Current.—We do not need, as above, to move the circuit carrying the influencing current. It will serve the same purpose if we leave the influencing circuit at rest, and simply start and stop a current in it. This will be equivalent to having a steady current in it and making it approach and recede from the second circuit.

On starting the current, then, in the inducing or primary circuit, we will have an oppositely directed current induced in the influenced or secondary circuit, and on stopping the current in the primary we will have a direct current induced in the secondary circuit. The above phenomenon is often called mutual induction. It can be studied by laying two long wires side by side, putting one in circuit with a battery and key, and the other in circuit with a galvanometer. On making with the key so that a current starts in the direction A B, the galvanometer will give a throw indicating a momentary current in the direction $\overrightarrow{DC}$.

On breaking with the key the galvanometer will give a throw indicating a current in the direction $\overrightarrow{CD}$. (Fig. 28.)

76. SELF-INDUCTION.—But inductive effects are possible without a second circuit. Two different parts of the same circuit may act on one another, *e.g.*, two different turns in the same spiral. A current rising in such a spiral will act inductively on itself, tending to produce a reverse current whose effect will be shown in a retardation of the rise of the main current. This is the self-induced current at "make."

Again, on stopping a current in a circuit, a momentary direct current will be produced, and its effect will be manifested in a tendency to prolong the life of the dying current. It is obvious that the effect of both, then, is to prevent either the sudden starting or the sudden stopping of a current of electricity. A similar effect is produced in a current of liquid by the *inertia* of the matter. Hence, the above phenomenon of self-induction is sometimes referred to as the *inertia* of electricity. We shall attempt to explain later the real cause of it.

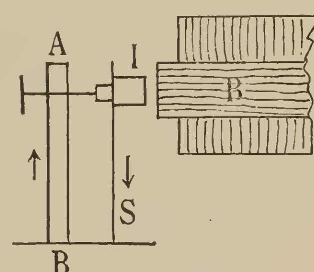


FIG. 29.

77. RUHMKORFF'S INDUCTION COIL.—A very important peculiarity of induced currents is that by using suitable secondary circuits we can get either a much higher or a much lower electromotive force than that of the primary, attended by a much smaller or much greater current, respectively. This is of great importance in apparatus which employs induced currents, such, *e.g.*, as Ruhmkorff's induction coil. An induction coil consists essentially of a *primary coil* or bobbin, which can be slid into a *secondary coil.* The primary coil usually contains an iron core, to heighten the effect. Subsidiary parts are an *interrupter* and a *condenser.* In accordance with the above remark, the secondary is made of a large number of turns of small wire, so as to largely increase the induced electro-motive force, and the primary is made of a few turns of stout wire, so as to afford a large current and decrease the effects of *self-induction.* On rapidly making and breaking the current in the primary, a succession of momentary currents, alternately reverse and direct, will traverse the secondary. This "make and break" can be best done automatically by an interrupter.

The Interrupter.—A bundle of soft-iron wires is inserted in the primary coil. When the current passes, this bundle becomes an electro-magnet, and attracts a piece of soft iron attached to a vertical spring, S. Parallel to the spring is an upright, A B, through which passes a screw, which presses against the spring, and the current of the primary is led through this upright, screw, and spring. On the breaking of the current by the attraction of I the bundle ceases to be an electro-magnet, and so I

is released, whereupon the circuit is again completed and again the current passes, and I is attracted. Thus we have a succession of momentary currents in the primary. (See Fig. 29.)

The Condenser.—This consists of sheets of tin-foil separated by dielectric sheets of paper soaked in paraffin. It is connected with the primary in such a way that (1) when the primary is broken the electricity of self-induction flows into the condenser, and so causes no spark at the interrupter; and (2) when the primary is made the condenser is discharged into it, and so causes the primary to grow very slowly, and thus greatly decreases the spark in the secondary at making of the primary.

The net result is that the currents induced in the secondary at make

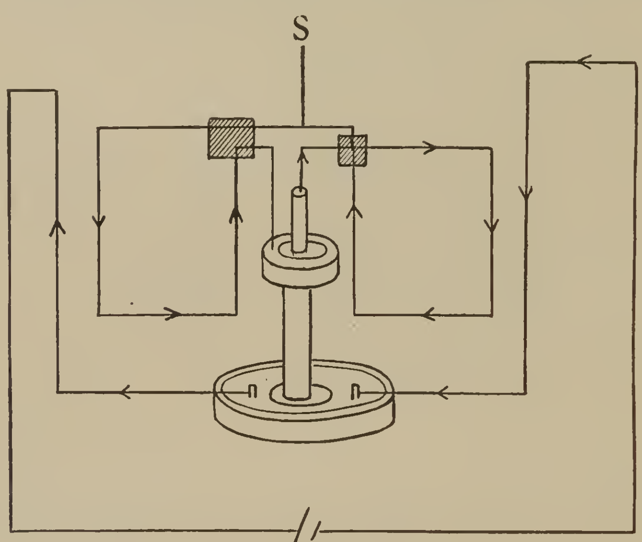


FIG. 30.

of the primary become very negligible compared with those produced at break of the primary, and so we have in effect a succession of currents in the same direction and of very high potential.

78. MAGNETO-ELECTRIC MACHINES.—So far as the generation of a current in a coil of wire is concerned, it makes no difference whether we move the magnet and keep the coil stationary or move the coil and keep the magnet stationary. The only thing requisite is *relative* motion.

In a magneto-electric machine two parallel bobbins of wire, each containing a soft-iron core, are whirled rapidly around an axis midway between them. Thus the bobbins come alternately in front of the poles of a poweful permanent magnet, and thus the cores are rapidly magnetized alternately in opposite directions, and so on in a circuit including both the bobbins alternate currents are generated in rapid succession. A *commutator* attached to the rotating axis reverses the currents at

every half revolution, so that all the currents are turned in the same direction.

79. ATTRACTION AND REPULSION OF CURRENTS.—Since magnetic poles attract and repel each other, and currents even in straight conductors have magnetic fields of force, it is natural to expect that currents will exhibit attractions and repulsions.

Ampère was the first to establish the laws of such attractions and repulsions. His conclusions as to all currents can be readily verified by such a simple apparatus as is shown in Fig. 30.

It will then be found that the currents attract each other where running in the same direction and repel where running in opposite directions.

The laws for oblique currents can be readily deduced from the foregoing. For if two parallel currents be shifted so as to become somewhat inclined to each other, then they will both run away from, or one away from and the other toward, the common apex, according as they were formerly, in the same or in opposite directions, respectively. Hence, oblique currents attract if both run away from the common apex, and repel if one runs away from it and one toward it.

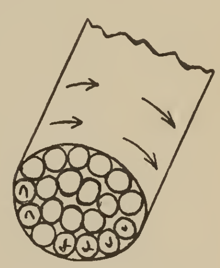


FIG. 31.—NORTH POLE.

80. AMPÈRE'S THEORY OF MAGNETISM.—Before proceeding to consider what electricity is, we may first get magnetism out of the way by reducing it to electricity, and here we are treading on pretty firm ground. For it will be remembered that in § 34 we saw strong reason for believing that even the ultimate particles of a magnet were magnets also. Now, absolutely all the behavior of a magnet can be imitated by an electrical current in a circle or helix. Hence we have a strong hint that the ultimate particles of a magnetic substance contain little circulatory currents, which, just like larger ones, ape the behavior of a magnet.

It will be remembered that the magnet to which a circular current was equivalent had its axis perpendicular to the plane of the current. Hence, according to this theory magnetization consists in making these molecular currents wheel all facing the same way with their planes perpendicular to the length of the magnet which they make up, *i.e.*, with their planes perpendicular to the lines of magnetic force.

We cannot take space to enumerate the numerous, almost conclusive arguments for this theory. One only we shall mention,—a remarkable phenomenon discovered by Faraday. Light that has its vibrations reduced to one plane is said to be plane polarized. Now, there are certain crystals and solutions that have a peculiar effect on such light, namely, they rotate the plane of polarization. Faraday discovered that when plane polarized light was passed through certain substances (notably, "heavy" glass) which were in a strong magnetic field, the direction of the rays of

light being the direction of the lines of force, a similar rotation of the plane of polarization took place. But there was a remarkable difference between the two cases. If the light were reflected back through the crystals its twist would be taken out, but if the same thing were done with the light rotated magnetically the twist would *be doubled.* This can only be explained on the supposition that in the magnetic field there is some kind of rotation going on around axes parallel to the lines of force.

WHAT IS ELECTRICITY?

81. NATURE OF ANSWER.—It is well to realize at the outset exactly what answer may be expected to the question, "What is electricity?" Since certain famous experiments performed by Dr. Hertz, of Germany, a few years ago, it has been a common popular mistake to suppose that we know what electricity in its essence is. This is as serious a mistake as to suppose that the establishment of the kinetic hypothesis tells us what matter is. What each does is simply to let us have a faint glimpse into the mechanism by which electrical and material phenomena are brought about; that is all. About what electricity is we *know* as yet practically nothing, and probably will never know fully. But we do now know positively something of the way in which certain electrical phenomena, chiefly those treated under the head "Electrical Radiation," are brought about. In a word, what electricity is has only been answered by certain dim speculations; but assuming a something, we know not quite what, called electricity, we can pretty clearly explain certain electrical phenomena.

It would, perhaps, be more satisfactory to take up the known and clearly settled first, and then indicate the unsettled speculations; but this would necessitate an order that would be likely to confuse the reader, so we shall take the subject up in the logical order, and take care to point out the known and the doubtful.

82. ELECTRICITY IS NOT ENERGY.—A common answer to the question, "What is electricity?" is, "Electricity is a form of energy." In preceding sections we have frequently spoken of electrical energy, or energy of electrification, or energy of the electrical current. But none of these phrases imply that the electricity itself is energy, just as though two masses attracting each other gravitationally (such as the earth and the moon) form a system having a certain amount of potential energy, and matter in motion has kinetic energy, yet in neither case is the matter itself energy. Similary, two so-called charges of electricity attracting and repelling each other form a system having potential energy and electricity in motion has kinetic energy; yet in neither case is the electricity itself energy.

Again, the energy of a charged conductor is the work we would have to do in charging it. Its potential, V, is the work done in bringing unit charge up to it from a place of zero potential. The work done in bringing Q units up will then depend on the product Q V. Hence, the

energy of the charge is proportional to the product Q V. Hence, it is obvious that the charge Q itself cannot be energy. In this respect it differs markedly from heat. The energy of a charge of heat does not depend upon its temperature; it is the same whether it is heat in a warm body or heat in a cooler body. The heat itself *is* energy.

83. Electricity is a Thing, for it is Conserved.—In § 3 we stated that the test of a thing was whether it was conserved or remained always the same in quantity. If all the cases of electrification and flow of electricity that we have discussed be carefully considered, it will be found in all cases that electricity will stand this test. In the first place, this is evident as regards a voltaic current, for no such current will flow except in a closed circuit. If the circuit be not completed, but the gap be not too great, the current will jump across the gap, and so complete the circuit. In any other case there will be no flow. The electricity, in fact, behaves as a perfect and incompressible fluid.

In the second place, as regards a static charge of electricity,—as, for instance, a charge given to a Leyden jar from an electric machine,—it may be objected that here we have, for the time being, a flow into the condenser without any complete circuit. But here, too, we can show that there is a circuit completed, and that the electricity still retains its similarity to an incompressible fluid.

84. In Charging a Conductor Electricity is Elastically Strained Outward.—In § 29 we saw a remarkable parallel between the charge and discharge and the various residual charges and discharges of a Leyden jar, on the one hand, and the phenomena shown by elastic bodies when distorted, on the other hand. This in itself was enough to strongly support the view that the charging of such a jar meant setting up an elastic strain in the dielectric which separates the coatings, and that its discharge meant relieving this strain. Thus, the most important part in the whole phenomena is played by the dielectric.

To enable us to think of the matter more clearly, we shall use the following analogy, which represents the state of affairs very well and may be, probably is, much more than a mere analogy. We shall think of electricity as an incompressible fluid, filling all space, and a *dielectric* as a kind of elastic jelly in which what we call electricity is imbedded or entangled. Now, a property of such an arrangement would be that, if we tried to displace the electricity, we would meet with a certain amount of elastic resistance from the jelly, and when we released the particles from the distorting forces they would be immediately drawn back nearly to their original positions by the elastic force of the jelly. This is what takes place in charging a conductor. Electricity is forced into it, but acts like an incompressible fluid, so that in the conductor itself no change of density of the electricity is produced, but at the surface electricity is forced out into the dielectric, setting up such a strain as we have referred to above. This, it will be observed, accounts

for what we referred to in § 21, that electricity resides only on the surfaces of conductors. For we conceive of a conductor as permitting the electricity to flow freely through it, so that in the conductor there is neither strain nor condensation. Hence, in the body of the conductor there will be no change produced and the charge will only be manifested as elastic strain at the surface.

But the electricity in the dielectric is incompressible, so that when any layer of it is displaced outward it must displace the next layer outward, and so on. Where, then, will the process stop? Evidently, it will only stop when the strain reaches the surface of another conductor from which electricity has been withdrawn. Some electricity will, consequently, be forced into the conductor. But how does this conductor come to have a deficiency? Electricity must have gone from it to somewhere. If the whole process has been confined to these two conductors, evidently what has been taken from B must have gone to A. In other

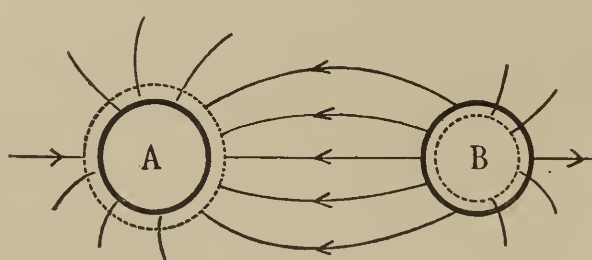


FIG. 32.

words, A has been charged positively and B negatively, and again the flow has been in a closed circuit from B to A by the machine and back to B by the dielectric. So A and B each contain as much electricity as at first, but the dielectric is in a state of strain, which will immediately force the electricity back from A to B, if we connect the two by a conductor.

85. Static Electrification is Potential Energy.—In § 8 we saw that an elastic spring, when stretched, tended to shorten and so do work, and so it possessed potential energy. In the same way, the strained dielectric separating two charged conductors is in a state of elastic distension, and contains, therefore, potential energy.

86. Paramount Importance of the Dielectric—No Action at a Distance.—The reader will notice that in the preceding the leading rôle is played by the dielectric or the non-conducting medium between charged bodies. It is, in fact, the dielectric that is charged, not the conductors. This recognition of the part played by the dielectric is what distinguishes the old one-fluid and two-fluid theories from the theories we now adopt. The older theories viewed the charges on two conductors as acting on one another directly at a distance, *i.e.*, without any assistance from the

intervening medium. From the time of Newton down, physicists have disbelieved in this action at a distance, though admitting it as a mathematical fiction. They believe now that when any two bodies act on one another,—viz., two conductors charged with electricity, two heavenly bodies (such as the sun and earth), or two magnets,—in all those cases the action is to be accounted for by considering what is happening in the intervening medium.

Direct action at a distance and action by an intervening medium should differ in this way: If a body acted on another directly at a distance, such action should be propagated instantaneously; whereas, if the action took place by means of the intervening medium, such transmission should not be instantaneous, but should have a finite velocity. It becomes, then, of the utmost importance to settle whether electrical effects are propagated with a measurable finite velocity. How this has been settled will be explained later (§ 92).

87. Function of a Machine, Battery, or Dynamo.—We see, then, that a circuit of wire is just as full of electricity when no current is circulating in it as when a current is circulating in it. The difference lies in the fact that in the latter case electricity is being pumped around the circuit by means of the "generator," as it is mis-called.

In the case in which a condenser is being charged, part of the flow consists in elastic displacement through the dielectric. This displacement will continue until the elastic reaction is equal to the displacing force, when the flow will stop, or until the strain in the dielectric ruptures the dielectric, producing a disruptive discharge.

88. Process of Conduction in Solids.—In a dielectric we can set up a state of strain with a tendency to spring back. In a conductor, though we may attempt to set up such a strain, it will be unavailing. It will break down as fast as set up, and thus the electricity will be handed on by a series of instantaneous disruptive charges, constituting a continuous flow in the conductor.

For clearness we may liken the process to the flow of water in a tube full of marbles. It will experience a frictional resistance to flow, and Ohm's law if interpreted tells us a remarkable thing about this resistance. For by Ohm's law the force urging the flow is proportional to the flow. Now, if there were no force opposing the flow the flow would not go on at a steady rate, but at an accelerated pace; or, if the force urging the flow were greater than the force opposing the flow there would still be a resultant force forward, and still an acceleration of the pace. Now, since there is no acceleration of the pace after the flow has become steady, it is evident that the urging and retarding forces must be equal; and since the urging force is proportional, accurately to the flow (which is Ohm's law), the retarding force must also be accurately proportional to the flow, or the frictional resistance is proportional to the first power of the speed. If we contrast this with the frictional resistance of the air to a falling

body, we will see that it is a remarkable result, for at low speeds the air offers a resistance proportional to the first power of the speed; at higher speeds the resistance is proportional to the second power, and at still higher to the third power. But in electrical flow the resistance is always proportional exactly tŏ the first power of the speed.

Now, when work is done against friction heat is produced. It is readily seen that the heat so produced when a current of electricity is forced along in opposition to friction will be proportional to the amount forced along in a certain time, *i.e.*, to the current. And it is also evident that the work is proportional to the force overcome; or, since this force overcome is equal to the driving force, the work is proportional to the driving force or electro-motive force acting. Hence, on the whole, the heat produced in the conductor, which represents this work done, is proportional to the product of the electro-motive force and current (*i.e.*, to E C), which is Joule's law (§ 65).

89. Connection between Conduction of Heat and of Electricity.—It is very evident that there is some close connection between the conduction of heat and that of electricity. For, as has been stated (§ 46), the heat conducting and electrical conducting powers of bodies run exactly parallel, or are exactly proportional. Moreover, substituting temperature for potential and quantity of heat for quantity of electricity, Ohm's law holds as accurately for heat as for electricity. Again, both spread out from a centre in a conductor on all sides, or are of the nature of diffusions.

Now we know that heating a body means quickening the *motions* of its particles, and we see that forcing electricity through a body heats it, or quickens the motions of its particles. This lends strong support to the idea that electricity is transmitted by to-and-fro vibrations of the particles of the conductor. A greater velocity of transmission will require a higher rate of motion of the particles, and this means an increase of temperature in the body, which is exactly what observation shows to attend an increase of current in a conductor. This seems highly probable as far as it goes, but must not be trusted to as anything but a hazy approximation to a complete explanation.

90. Atomic Unit of Electricity.—We saw by Faraday's law of electrolysis (§ 56) that if a quantity of electricity passed through an electrolyte, the quantity (by weight) of an ion it took with it depended on the atomic weight of the ion and its valency, and was proportional to the atomic weight divided by the valency. Now, since atomic weights mean the relative weights of the atoms, if we take weights of two substances in proportion to their atomic weights, these quantities must contain the same number of atoms. Hence, Faraday's law means that the passage of a certain quantity of electricity brings the same number of atoms to the electrodes, no matter what the substance is, except that in the case of a divalent element only half as many are brought, in a trivalent only

one-third as many, etc. This evidently amounts to saying that each univalent atom carries a certain amount of electricity, each divalent twice as much as a univalent one, each trivalent three times as much, etc., no matter what the substance may be or what the weight of the atoms.

Calling the charge carried by a univalent or monad element the atomic unit of electricity, a dyad atom carries two atomic units, a triad three, etc. This, then, is a natural unit of electricity. An atom of a substance is a perfectly definite mass of it, and now we see that each atom carries a perfectly definite charge of electricity, which charge is simply the atomic unit of electricity multiplied by the valency of the substance.

Magnitude of the Atomic Unit.—From the roughly-known number of atoms in a certain quantity of gaseous ion set free by a known current of electricity we can calculate roughly the size of the atomic unit. It turns out to be about the hundred-trillionth part of a coulomb. This is an exceedingly small quantity, but we have to remember the smallness of atoms of matter and their nearness together. If we compare the electrical attraction between them or their chemical affinity with the force with which they would attract each other according to the ordinary law of gravitation, we find that the electrical attraction is ten thousand million million million times the greater!

91. Chemical Affinity an Electrical Phenomenon.—Hence, a remarkable parallel between the atom of matter and the atomic unit of electricity. The atom of matter is (for the same substance) of invariable weight, and is the smallest quantity of the substance we ever have to deal with. The atomic unit of electricity is an invariable quantity, and is the smallest quantity we have to deal with. Moreover, every univalent atom of matter carries one atomic unit of electricity, every divalent atom of matter two atoms of electricity, etc. Thus, the valency of an atom is simply proportional to the number of atoms of electricity it carries.

The question at once suggests itself, May not the valency be caused simply by the number of units of electricity the atom carries?

A dyad atom (*e.g.*, O) attracts to itself two monad atoms (*e.g.*, H), giving H_2O. It will take neither more nor less than two. Now, a charge of two negative atomic units of electricity on O would attract the unit charges of positive electricity on *two* atoms of H, neither more nor less. Thus, electrical attractions account for "chemical affinity," and there can be but little doubt that this is the true explanation.

92. Propagation of Electro-magnetic Influence.—We have so far been referring to what goes on in the transmission of electricity from place to place along a conductor; but we had several instances of a current producing effects across the dielectric surrounding the current. For instance, a current acts on a magnet separated dielectrically from it, and even where there is no magnet it sets up a field of magnetic force. Again, a current induces a current in a neighboring circuit separated dielectric-

ally from it. So that a current exerts both electrical and magnetic influence across an intervening dielectric. These phenomena are called electro-magnetic inductions.

Now, in § 86 we referred to the two possible views of this action: (1) that it was direct action at a distance; (2) that it took place by an intervening mechanism. We proceed, then, to show that the latter is the true explanation,—that, in fact, electro-magnetic induction is a wave phenomenon propagated through the medium in successive pulses, some-

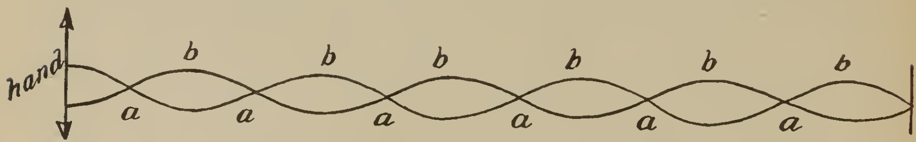


FIG. 33.

what like water waves on the ocean, or sound waves in air. But for the moment we shall offer no description of the nature of the wave. The question simply is, Is it wave motion?

93. INTERFERENCE.—One of the striking properties of waves is that they can interfere, so as to annihilate one another at some places and re-inforce one another in other places. Any one who has watched two systems of water waves coming from different directions around a headland and meeting knows that at some places they produce a calm, namely, where the crests of one system fill up the troughs of the other, and at other places they produce waves of double height, namely, where crest falls on crest. The same is true if waves are reflected from a vertical cliff: the direct and reflected waves interfere, producing similar effects.

FIG. 34.

To take another example, any one may, by tying an end of a long rubber tube to a distant wall, stretching it out, and moving the end in the hand rapidly up and down, produce an interfering system of direct and reflected waves. In the system so set up it will be observed that certain points (*a*) are always at rest, and certain other parts (*b*) always in motion. The former are called *nodes*, and the spindle-shaped parts between the nodes are called *ventral segments* of the stationary waves. (Fig. 33.)

A complete wave-length is twice a ventral segment in length. Now, interference is a characteristic of all waves, and if electro-magnetic induction be a wave phenomenon it must show the same.

94. VIBRATOR AND RESONATOR.—The difficulty, however, in testing this question is how to start suitable waves, and how to detect and measure them. In the first place, we must have something corresponding to the hand in the above to start vibrations. This we shall call the vibrator. Its vibrations must not be too slow, or the waves will be too long to deal with.

Now, if we take a pair of conductors, as in Fig. 34, and highly charge one, it will discharge through the knobs to the other, but the action will not stop there. Just as in the case of the oscillating discharge of the Leyden jar, there will be a return rush from B to A, then again from A to B, etc. The periods of these return oscillations will be exceedingly short. If the plates are about sixteen inches square, the oscillations will number thirty millions per second.

Now, how to detect the waves: here we make use of the principle of resonance. If an organ-pipe be tuned to exactly the same pitch as a tuning-fork, then when the tuning-fork is sounded at the mouth of the pipe the latter will sound in sympathy. What is called the frequency of vibration is the same in both fork and pipe, and the pipe is said to *resonate* to the fork. How can we get an instrument that will sympathize with an electrical vibrator? The most natural would be a plain circle of wire (Fig. 35), of such a length that the currents induced alternately in opposite directions by our vibrating primary currents would run around in the same time as the original vibrations. What length it will need to be will depend altogether on how rapid the vibrations of the vibrator are. With the plates mentioned above seven feet is a suitable circumference for the resonator. How, finally, are we to observe the oscillations of the induced currents in this resonator? By making a small gap in it, and noticing the currents dashing across the gap in a spark when, after a few concurrent rushes, they have gained sufficient volume.

FIG. 35.

Now, we are prepared *to feel for* the electro-magnetic waves. The vibrator is set up vertically, a reflecting sheet of zinc set up at a distance parallel to it. Just as in the waves reflected from the wall along the

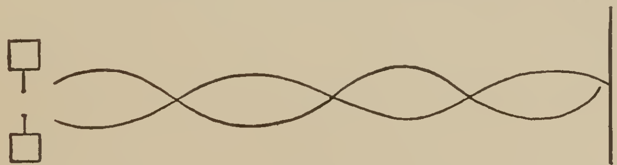


FIG. 36.

rubber tube the electro-magnetic waves will be reflected from the zinc, and, interfering with the direct waves, will produce stationary waves. At the nodes of these waves the resonator shows no effect, but at the loops it sparks. Doubling the distance between two consecutive nodes we have the wave-length, or the distance traveled by the disturbance during one complete vibration of the vibrator, and, multiplying by the number of vibrations per second, we have the velocity with which the disturbance travels.

95. ELECTRO-MAGNETIC THEORY OF LIGHT.—The velocity thus determined turns out to be practically the same as that of light, and this is a

strong confirmation of the theory otherwise almost proven, that light waves are simply electro-magnetic waves, but of immensely smaller length than any ordinary electro-magnetic waves. Light waves are less than one-forty-thousandth inch in length, whereas the waves obtained as described are several feet or even hundreds of feet long,—a difference, it is true, immensely greater than that between the waves given by the highest note of a piano and the lowest note, but still a difference merely of degree, not of kind.

How could we get real light waves in such a way? By taking a vibrator rapid enough, *e.g.*, a Leyden jar small enough. If we calculate what the size of such a Leyden jar would be, we find its size about the size of a molecule, which has been otherwise roughly determined. This suggests that light waves are electro-magnetic waves excited by electric oscillations in the molecules of incandescent matter. But it is not necessary to imagine the atoms discharging like Leyden jars, nor yet to imagine that the electrical oscillations are pulses of electricity rushing backward and forward from end to end, as it were, of the atom, like the oscillations of water in a trough when one end has been raised and dropped. We know that the atoms are in vibration, their vibrations constituting heat; and these atoms being charged, the charges vibrate to and fro along with the atoms, and thus constitute alternating currents.

96. MAXWELL'S PROOF OF THE IDENTITY OF LIGHT AND ELECTRO-MAGNETIC WAVES.—Though Maxwell could not measure the velocity of such waves directly, he deduced from his theory a formula for the velocity, in terms, of the inductive capacity of the medium and its *magnetic permeability* which, on being filled in with the values of these constants for different media, gave practically the same number as that which expresses the velocity of light.

His formula may be very briefly explained thus: Newton showed that the velocity of sound waves in a medium of density (d) and elasticity (e) is

$$V = \sqrt{\frac{e}{d}}$$

Now, it will be remembered that k, the specific inductive capacity of a medium, is proportional to the capacity of a jar, with that medium as dielectric. This capacity is greater the greater the electric displacement the medium allows, and this electric displacement varies inversely as the elastic resistance to displacement; so that the specific inductive capacity appears as the reciprocal of the elasticity. Hence, in the above formula we write $\frac{1}{\kappa}$ instead of e.

Again, the magnetic permeability of a substance can be shown to be analogous to the density of ordinary matter; and this magnetic permeability, which is simply the ratio in which a magnetic field is strengthened at any point by the presence of that substance instead of air at the

point, is readily determined by proper methods. It is usually denoted by $\dot{\mu}$. Thus, the foregoing formula of Newton's becomes, for the case of electro-magnetic waves,

$$V = \sqrt{\frac{1}{\kappa\,\mu}}$$

Now, the velocity of light in various substances is deduced from their refractive indices, and so we can test the agreement between these two velocities. This agreement, though not perfect, is close enough to form a convincing proof of the theory.

97. VIBRATIONS CONSTITUTING AN ELECTRO-MAGNETIC WAVE.—When a current is started in a conductor, $\overrightarrow{A\,B}$, it immediately sets up a field of magnetic force, and we saw that the lines of force of this field were circles inclosing the current (§ 38). Now, it is proven that this magnetic influence of the current spreads out not instantaneously, but with a

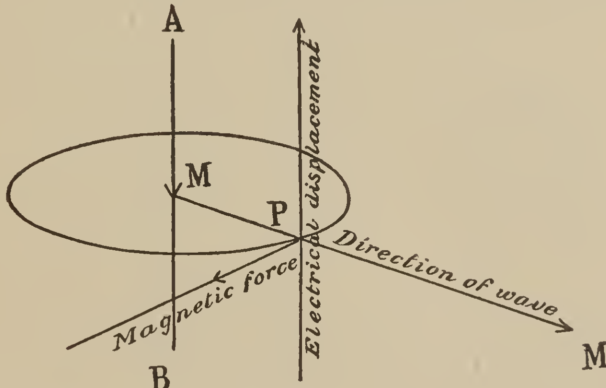


FIG. 37.

measurable velocity, namely, that of light. We may represent this by thinking of the circles widening out with that speed in all directions. The circles are always perpendicular to the radial direction, such as M M, in which they are carrying the magnetic influence of the current. Now, this direction is the direction in which the waves travel, the front of the wave being, of course, at right angles to the direction in which it is traveling. Hence, the lines of magnetic force lie in the front of the advancing waves.

Again, the growing current has an electrical influence such that, wherever it finds a conductor, it will set up a (momentary) current in it in a direction opposite to itself; or, at a point where it finds a dielectric, it will set up a strain in the dielectric, the direction of the strain being opposite to that of the original current. This direction, also, is perpendicular to the direction in which the wave travels; that is, it lies in the front of the advancing wave. But at the same time it is perpendicular to the (circular) lines of magnetic force.

Now, it will be remembered that the current in the vibrator is one that frequently has its direction reversed. Whenever the direction is reversed the direction of the electrical displacement at P is reversed and likewise the direction of the magnetic induction. These are the two vibrations that together constitute the advancing wave, viz., a vibration of electrical displacement perpendicular to the direction of motion of the wave, and a vibration of the direction and magnitude of the magnetic force perpendicular to both the others.

How to picture these two vibrations and their co-existence is a difficult problem, but it may be simplified by means of the following analogy due to Maxwell.

98. Mechanical Model illustrating Electro-magnetic Waves.—There is the most complete proof that wherever magnetic force exists we have something rotating about axes parallel to the direction of the force. This proof is supplied by the rotation of the plane of polarized light on traversing a magnetized medium parallel to the lines of magnetic force. Maxwell describes the field as filled with *molecular vortices* rotating around the lines of force. These rotating parts are also elastic and compressible. Let us think of two wheels—M and M′—of India rubber representing two of these magnetic vortices, with another smaller wheel between them representing a particle of electricity and tethered by springs on either side. Suppose M set in rotation clockwise by an electromagnetic wave reaching it, M will then tend to turn E and E to turn M′. But M′ has inertia and will not be started all at once. Hence E in its effort to start M′ will be by the reaction pulled downward, thus stretching the upper spring. Then it gets M′ into rotation in the same direction as M's rotation. Thus we have a representation of magnetic rotation and electrical displacement.

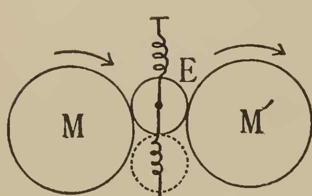


Fig. 38.

What happens next depends on whether the current that started this field is a steady current or whether it is a rapidly alternating current. If the latter, what happens is this: The rotation of M and the displacement of E reach maxima, and then when the current decreases and reverses the rotation of M ceases and reverses, thus dragging E up and gradually setting M′ also into rotation in the opposite direction. Thus, for every reversal of the current we have a reversal of the rotation of the Ms and a reversal of the displacement of the Es, and so the electro-magnetic wave is propagated.

It will be noticed that the axes about which the magnetic rotations take place are perpendicular to the plane of the paper and the direction of the electrical displacement is up and down in the plane of the paper, and so both are perpendicular to the direction M M′ of the advancing

wave or lie in the front of the wave. In this respect the model represents the wave truly.

99. Model illustrating Induction of Currents.—Suppose this magnetic rotation comes to a conductor, what happens then? In a conductor there is no elastic restraint of the electricity; so a stream of electrical particles is forced past by the rotating magnetic vortices, thus giving rise to an electric current until M′ has acquired the velocity of rotation of M and then the stream stops. So there is a temporary induced current, and it is readily seen from the model that this temporary induced current in conductor B is opposite to the inducing current in A. Again, at break of A the magnetic whirls between A and B gradually cease, but those beyond B for a moment keep on, thus causing a momentarily induced current in the opposite direction to the first one; that is, in the direction of the current in A.

Again, if we think of A itself on first making A, there is a reaction

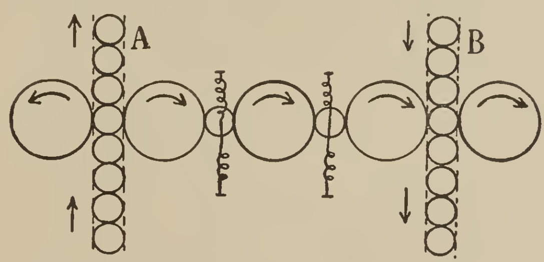


Fig. 39.

of the adjacent magnetic whirls to being set in motion, and this shows itself as an electro-motive force resisting the starting of A. At break of A the magnetic whirls keep on for a moment, thus tending to keep the current up and causing a temporary induced electro-motive force in the direction of the original primary current in A.

100. Function of a Conductor in the Passage of a Current.—We have seen that when a current is started at a seat of electro-motive force, systems of magnetic rotations and electrical displacement are started out in all directions in the surrounding dielectric. Hence, also, energy is being radiated. What becomes of this energy? Part of it passes off into space, but a comparatively small part. Most of it converges back on the conductor that is said to convey the current. There the strains break down and their energy is converted into heat energy. Thus, there is a continual flow of energy into the conducting wire from the dielectric, and so a chance given for continual new supplies of energy being given to the dielectric. When the current does work, such as turning a motor, it is not the energy in the conductor, but the energy of the dielectric in the neighborhood that is transferred to the motor. Thus, we see that the conducting wire plays the comparatively insignificant part of merely directing the flow of energy through the dielectric.

Whatever energy falls into itself is wasted as heat. The dielectric plays the all-important part of conveying the useful energy.

From this it is apparent also that electricity is urged along through the conductor not by pushes from behind, but by side forces, *rubbings*, as it were, all along the length of the conductor.

101. Dual Nature of Electricity.—We have seen that electrical effects are conveyed by the medium called the luminiferous ether. Is, then, electricity simply the ether?

Now, there are many things that strongly suggest that there are really two electricities. In electrolysis, it will be remembered, there was a separation of the atoms constituting the molecules of a liquid and a procession of the electro-positive atoms down the stream toward the cathode, and a similar procession of the electro-negative atoms up the stream to the anode. This is a strong suggestion of a dual nature for electricity, but it is by no means the strongest. Even in electro-statics such a view seems called for, by the fact that electro-static strain does not alter the volume of a dielectric, suggesting that the process consists in the displacement of something else inward.

Again, we must regard electricity as in some sense a substance, and therefore possessing inertia. Now, not the slightest trace of momentum has ever been shown by a current. Again, any one who has rotated a gyroscope and noted the difficulty of changing the direction of its axis while it is in strong rotation, knows what is meant by moment of momentum. Now, the powerful currents that can be sent around an electro-magnet should make it also difficult to turn into a new direction, unless it be that the effect of a current in one direction is neutralized by that of a current in the opposite direction. These and other facts suggest that there are really two electricities.

Since, then, the ether is somehow intimately connected with electricity, and there are probably two kinds of electricity, it may be that the two electricities co-exist in the ether in somewhat the same way as hydrogen and oxygen exist together in water. When one goes in one direction the other goes in the other direction, like the procession of the ions in the electrolysis of a liquid. In a dielectric there is difficulty in separating the components, and even when separated a short distance they will spring back, thus giving the dielectric the elastic property to which we have several times made reference. If too far separated they do not return, but fly apart, causing what we call a disruptive discharge. Again, in a conductor, the bonds connecting the two constituents are somehow relaxed, so that they are readily separated. This, however, is merely a guess quite unverified, but looking very plausible.

ANIMAL ELECTRICITY.

By WESLEY MILLS, M.A., M.D., L.R.C.P.Lond., F.R.S.Can., etc.,
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Animal electricity is a subject as wide as it is inviting. Electric phenomena have been demonstrated in connection with the development of the embryo, with the secretory processes of glands, with the heart-beat, etc. In fact, the subject has been sufficiently developed to warrant the surmise that all vital phenomena may have electric as they have chemical concomitants; though such is yet far from proven. The electricity of muscles and nerves has been investigated with great thoroughness, and will be found treated in another part of this work. When it was discovered that certain fishes possessed electric organs, these naturally became the subjects of investigation by some of the leaders in physics, as Faraday; and of electro-physiologists, including that great master and, in fact, discoverer of what is most important in the electricity of muscles and nerves, Prof. E. du Bois-Reymond.

His researches, together with the later ones of Professors Burdon-Sanderson, Gotch, and Ewart in Great Britain, make up the most valuable part of what has been achieved in this direction up to date. Were the space at our disposal for this subject not so limited it might be interesting to glance at the labors of others, imperfect as they are; but, under the circumstances, it will probably be wiser to attempt to lay before the reader, in the briefest way, an account of the methods and results of those investigators only who have most advanced the subject, and whose previous researches in kindred fields have won our confidence.

The principal-known electric fishes are the *Gymnotus*, or electric eel; the *Malapterurus*, or sheath-fish; the *Torpedo*, and several other species of rays.

The *Gymnotus electricus* is the most powerful of all known electric fishes, and may attain a length of five or six feet. It frequents the marshes of Brazil and the Guianas, and its shocks are capable of stunning, if not actually killing, the largest animals. Humboldt informs us that the direction of certain roads had to be changed in consequence of the numbers of horses annually killed as they passed through the ponds which these fish inhabited. Its electric organs consist of two pairs of long structures situated immediately beneath the skin,—one pair on the back of the tail and the other along the anal fin. The organ is made up, as is usual, of cells filled with a sort of gelatinous material, and in this creature are so small that two hundred and forty have been counted in

the space of one inch. It is estimated that about two hundred nerves are supplied to the whole apparatus, these being derived from the anterior branches of the spinal nerves, and, as applies to the nerves of all electric fishes, are larger than those supplied to other parts. It is clear that an animal capable of giving such powerful shocks is not as well adapted for nice experiments as less-powerful fishes.

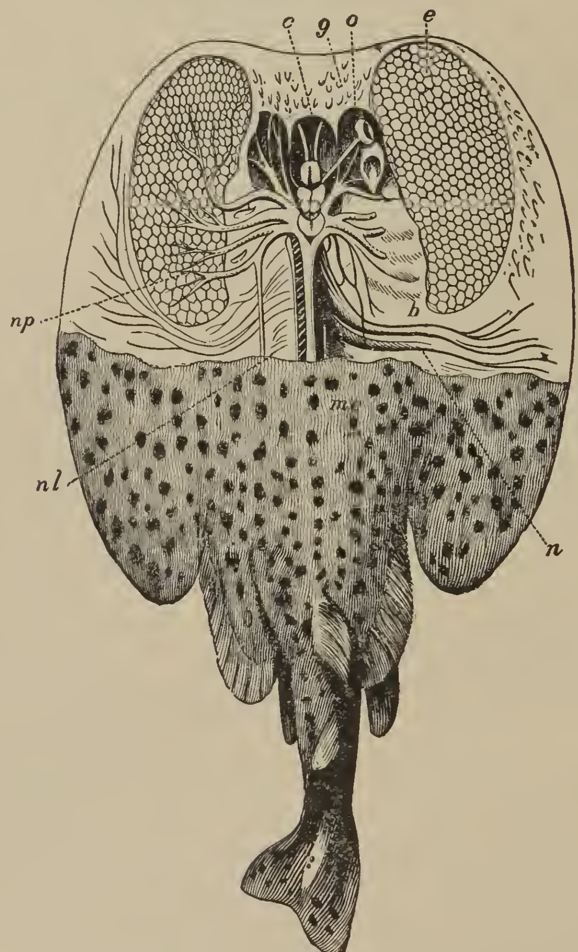

FIG. 1.—THE ELECTRIC FISH TORPEDO, DISSECTED TO SHOW ELECTRIC APPARATUS. (*Huxley.*)

b, branchiæ; *c*, brain; *e*, electric organ; *g*, cranium; *me*, spinal cord; *n*, nerves to pectoral fins; *nl*, nervi laterales; *np*, branches of pneumogastric nerves to electric organs; *o*, eye.

I. Following the historical development of the subject, we proceed to give some account of the important researches of Prof. Emil du Bois-Reymond on the tropical sheath-fish, the malapterurus. This fish is found in the rivers of Africa, including the Nile, specimens occasionally

reaching a length of four feet. The electric organ extends over the greater part of the body, lying beneath aponeurotic membranes under the skin. The cells making up the organ are rhomboidal and filled with a somewhat firm jelly. The nerve-supply consists of a single strong fibre, which gives off branches to different parts of the organ. The minute structure of electric organs will be described and illustrated later. A general idea of an electric fish may be obtained from Fig. 1.

Professor Goodsir, of Edinburgh, supplied Professor du Bois-Reymond with the specimens he first used for experimentation. They were kept in a trough constructed with a view of preserving a constant supply of fresh, well-aërated water of a suitable temperature, and were fed at first on earth-worms and later on strips of beef. The specimens were small, without barbels, young, and mostly females. The color of the fish varied with the degree of exposure to light. In darkness they became blackish, and when fatigued by experiments pale, returning to their former color after resting for a few days. They became more lively at

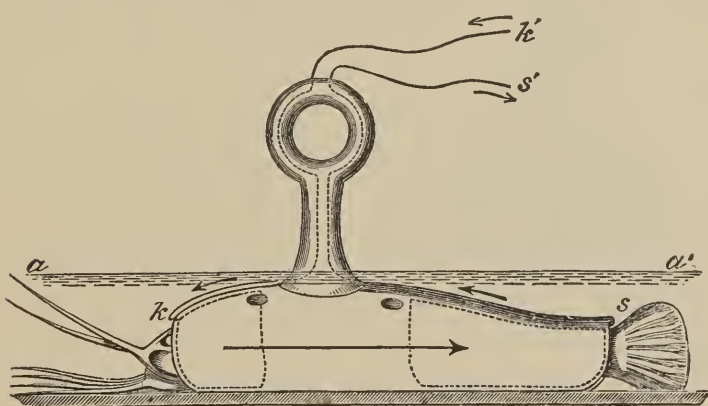

FIG. 2.

night; in fact, showed fear of light. When other fish were put in the same tank with them they immediately discharged their electric organs successively, the victims soon drifting about apparently lifeless. When left in the tank such fishes died, but if withdrawn they recovered. A frog under similar circumstances stretches out as if strychnized. In bad health the electric power was correspondingly diminished.

Method of Experiment.—The malapterurus being a fresh-water fish, not large, tenacious of life, and the electric organs supplied by a single large nerve originating in a giant ganglion-cell, is much more easily investigated in many respects than some others. Fig. 2 will give an idea of the fish, the apparatus used, etc. It will be observed that the animal is almost entirely covered with a gutta-percha case having linings of tin-foil at the two extremities, indicated by the dotted lines. These communicate by means of strips of tin-foil (*k s*) covered by insulating

material, with the handle where they are soldered to small copper plates, in which the wires end. *a a′* denote the surface of the water in the tank. The arrows indicate the direction of the currents.

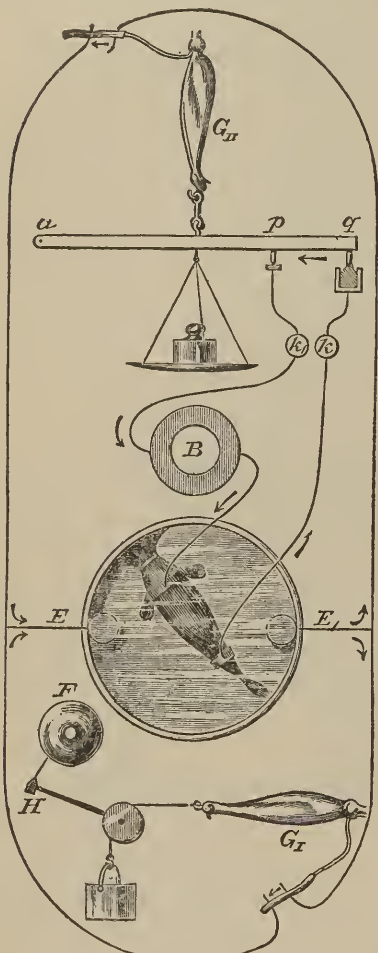

FIG. 3.

E and E_I, zinc electrodes in the trough containing the fish; *F*, *H*, G_1, the bell, hammer, and muscle arranged to form an alarum; *a*, *p*, *q*, lever of the frog-interrupter; G_{11}, its muscle; *p*, the platinum point which rests upon the supporting plate; *q*, amalgamated copper wire which dips into mercury; *k*, k_I, keys; *B*, galvanometer. The action of the interrupter is such that only one shock can pass through the galvanometer, for by the contraction of the muscle G_{11} the galvanometer circuit is broken at *q* and not again closed. The alarum, of course, goes on ringing.

Another ingenious and much-used apparatus is that shown in Fig. 3, illustrating the "frog-alarum" and "frog-interrupter," which in great measure explains itself. By means of the "frog-alarum" it was always possible to learn when the fish being experimented on gave a shock, and by the "frog-interrupter" only one shock was allowed to pass through the galvanometer, no matter how many were given. We may now deal briefly with the results of the experiments:—

Subjective Test.—By touching the head and back of the fish, or seizing it between the wetted hands, shocks varying in intensity, but powerful for the size of the animal, may be perceived.

Direction of the Shock.—As shown by the arrow in Fig 2, the current passes from the head toward the tail, *i.e.*, in a direction opposite to that of the shock of the gymnotus.

Physical Investigation of the Shock.—The principal results were: Polarization of electrodes, but no distinct electrolysis of water resulted. Passage of a spark was observed by the use of a special apparatus. Induction, magnetization of soft iron, and electric attraction were all demonstrated.

Tensions.—The poles of the organ lie at the head and the tail, and the posterior half of the organ acts more feebly than the anterior, owing to greater resistance in the former.

Relative Immunity from Electric Shocks.—Both Humboldt and

Collodon had expressed the opinion that electric fishes do not shock each other when their batteries are discharged, and du Bois-Reymond's experiments proved that the malapterurus is not affected by currents from a battery that suffice to kill other fish. The torpedo is viviparous, yet its young are not killed *in utero* by its own discharges. It appears, then, that electric fishes can withstand both their own and outside shocks; and although du Bois-Reymond discussed the reasons of this immunity, he did not satisfy his own mind on the subject. Of course, such fishes are not absolutely unaffected, and could, no doubt, be killed by a very powerful electric discharge.

The Isolated Living Electric Nerve and Organ.—It will suffice to note that such a nerve acts like any other nerve under similar circumstances,—*e.g.*, when laid on the organ of the same side and tetanized, a nerve-muscle preparation responded by tetanic contractions. Like muscle, fresh electric organ is neutral, becoming acid on standing; but when kept in warm water a short time it becomes acid, in this respect resembling the central nervous system.

II. We shall now proceed to state the results of the same physiologist's researches on the *Torpedo electricus.*

Prof. du Bois-Reymond first used for experiments specimens kept in the Berlin Aquarium which were brought from Trieste, and these were succeeded by others of a more definite character made upon fish supplied through the aquarium at Trieste. The animals used belonged to the species *Torpedo marmorata*, and were between twenty-five and thirty-six centimetres in length. They were kept in tanks in the Berlin Aquarium, burrowing in the gravel at the bottom and apparently unconcerned as to the presence of other fishes. When unconfined they eat fish of considerable size, which they first paralyze by their shocks; however, in confinement they do not seem to have taken the cut-up fish thrown into the tanks. When experiments were about to be performed they were removed from the tanks by means of a landing-net to a tub, and thence transferred to the experimental trough described below, and illustrated in Fig. 4.

The arrangement shown assumes that a shock is to be imparted to a human being; so that there are two handles in the experimental circuit, to one of which, Hv, the wire v' is conducted. The fish represented in cross-section is lying in a glass vessel thirty centimetres wide and ten centimetres deep, on the bottom of which there is a circular zinc plate of about the same width as the body of the animal, forming a ventral shield $v\ v^{\circ}$, a portion of which, $v\ v'$, was bent and hung hook-like over the side of the vessel. One end of the experimental circuit was brought into contact with this hook; a circular piece of flannel, $f\ f'$, soaked in sea-water, was laid on the ventral shield to prevent the edge of the dorsal shield $d\ d^{\circ}$ from touching the ventral. The specimen rests on the

flannel. The dorsal shield is an arched zinc plate with the edge turned up, the upper surface of which is lacquered and provided with a wooden knob in the middle, through which the leading-off wire, d' Hd, is conducted, insulated, to the second handle. There was just enough sea-water in the receptacle to cover the back of the fish, and no more. It will be noticed that there is a frog-alarum in the circuit, the arrows, as usual, showing the direction of the current; G is the gastrocnemius, with its nerve; T the bell, H the hammer, and E the weight.

Subjective Tests.—By means of this apparatus (Fig. 4) du Bois-Reymond succeeded in giving a shock to the students in attendance at

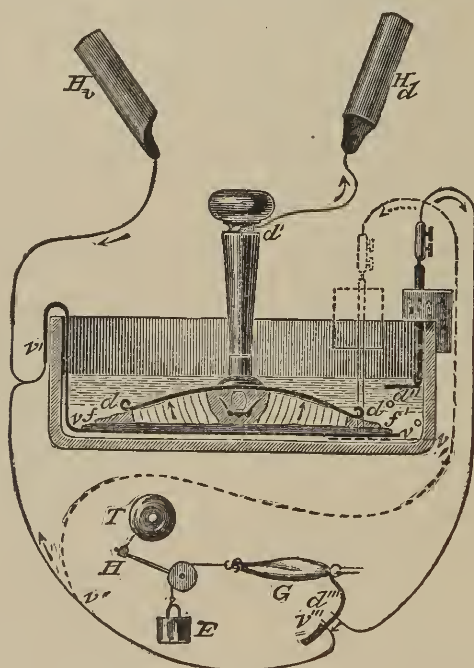

FIG. 4.

his lectures, who joined hands, after wetting them. Of course, the strength of the shock varies with the condition and size of the specimen. As a matter of fact, torpedoes seem to lose the power of giving vigorous shocks sooner in confinement than does the malapterurus.

Electrolysis of Iodide of Potassium.—By means of a special form of electrolyzer this physiologist, like Davy and Matteucci, got this salt decomposed, and, in addition, there appeared a spot at the primarily negative pole, owing to polarization in consequence of the electrolysis; so that there is a secondary current in the opposite direction to the primary, explaining the change in pole.

The Organ Current.—By this is meant, as opposed to the shock, a

current persistently generated through the electric organ, and usually in the direction of the shock. This organ current has been observed by others in the torpedo, in the skate, and in the gymnotus. Du Bois-Reymond found by the galvanometer that this current varied with the organ of the animal, and he made several measurements of its strength. According to Sachs, tetanus of the electric organ in the gymnotus weakens the current.

Secondary Electro-motive Actions of the Organ of the Torpedo and Irreciprocal Conduction.—By means of apparatus used to investigate allied phenomena in muscle and nerve du Bois-Reymond established some very interesting conclusions, which, however, may be stated briefly: "Internal polarization of the organ follows the passing of a current through it in the direction of the columns, which, like the polarization of muscles, nerves, and the organ of the malapterurus, is, under different circumstances, sometimes relatively positive, sometimes relatively negative, the conditions required for the appearance of both polarizations being generally the same in the latter as in the former." Different results were obtained, according to the direction of the current sent through the organ. This difference of strength of current must depend on either unequal electro-motive strength or unequal resistance. By "irreciprocal resistance" is meant that conduction may be better in the direction of the shock than in the opposite direction, and du Bois-Reymond was led to believe in its existence in the torpedo.

Electro-motive Actions of Electric Nerves in the Torpedo.—The eight electric nerves of this creature,—four on each side,—which can be prepared, without branches, of a length of three to four centimetres, and of an average thickness of two and a half millimetres, served admirably for the investigation of this subject. This part of the investigation was carried out by Professor Christiani, who found that the greatest electro-motive force obtained was more than twice as small as that of the nerves of the frog, more than three times as small as that of the nerves of birds or of mammals, excepting the horse, and over five times as small as that of the nerves of the lobster. One peculiarity Prof. du Bois-Reymond discovered himself, viz., that the peripheral transverse section shows greater negativity as regards the equator; though it seems probable that this is not, strictly speaking, a peculiarity of electric nerves.

Negative Variations of the Current of the Electric Nerves when in a State of Activity.—Carefully-conducted experiments established the negative variation, though there were associated phenomena difficult to explain.

Prof. du Bois-Reymond's Second Investigation of Living Torpedoes.

This confirmed some previous results and developed new ones, which we proceed to give.

Electro-motive Behavior of the Skin of Electric Fishes.—Employing

the usual methods of investigation of such phenomena, it was concluded that the skin of the torpedo behaves electro-motively like that of the gymnotus, in regard to the direction as well as the magnitude of the action, and like that of the malapterurus in direction, and in all three fishes the force is probably about equal.

Irreciprocal Conduction.—This apparent irreciprocity of conduction was shown to increase with the current density, to have its seat in every transverse lamella of the preparation, and to increase with the length of the columnar track which is traversed by the current.

Resistance of the Electric Organ.—The main conclusion is that the organ conducts best in the direction of the shock, but even in that case scarcely half as well as frog-muscle parallel to the fibres, and from seven and one-half to twelve times worse than the sea-water of the aquarium, and much worse still than sea-water of the Mediterranean; but in the opposite direction to the shock, from twenty to fifty-eight times worse than sea-water.

Further investigation showed that these differences are dependent on the vitality of the organ, for as this diminishes a condition of equality in conduction—*i.e.*, resistance—is approached. The advantage, to the fish, of this state of things is obvious; at all events, so far as the direction of least resistance is concerned, and on the principles of organic evolution, it is possible to understand why development should take place, as it usually does, in those ways, and those only, which are advantageous to the individual.

Researches of Professors Burdon-Sanderson and Gotch.

It is proposed now to give an account of the researches more especially of Professors Burdon-Sanderson and Gotch, with incidental reference to the work of some other investigators, including that of Professor Ewart, in the development of electric organs. These are detailed in two papers in the *Journal of Physiology*, vol. ix, Nos. 2 and 3, and vol. x, No. 4. in which researches the skate was the fish employed, the work being done in July, 1887, at the marine laboratory at St. Andrews.

FIRST RESEARCH.

Previous Anatomical Researches of Stark, Robin, and Max Schultze.—These are summarized in the paper of Sanderson and Gotch, from which the present writer extracts. Stark discovered the electric organ of the skate in 1844. Robin made a communication to the Academy of Sciences on the same subject in 1846, and at greater length in 1865.

He describes the organ as consisting, in large skates (seventy centimetres wide), of a spindle-shaped structure fifty centimetres in length, which is placed on either side of the vertebral column of the tail. It is gray in color and semi-transparent, and is traversed transversely and lon-

gitudinally by septa, which divide it into compartments, of which the form is that of a lozenge. The cephalic proximal end of each organ is sheathed in concentric layers of muscle. By its median face it is in relation with the dorsal and ventral spinal muscles, but between these there is a space along which it touches the vertebral column, and here the blood-vessels and nerves enter it. The rounded external part of the surface is subcutaneous. The blood-supply of the organ is derived from the intervertebral branches of the caudal artery; the veins join corresponding branches of the subcaudal vein. The arteries find their way by means of longitudinal septa to the discs, to be immediately referred to. The nerves are derived partly from the anterior roots of the nearest spinal nerves, partly from the trunks of those nerves beyond the junction, and are distributed in a manner similar to the arteries until they approach the discs, where their mode of termination will be described later.

M. Robin's description of the minute structure of the organ is as follows: He regards the discs already mentioned as its essential elements. These, which are polygonal in contour and about three millimetres wide, are separated from each other by transverse septa. The anterior surface of each of the discs is smooth, the posterior alveolated. They are arranged in piles (columns), which are separated from one another by longitudinal septa, and which vary in number according to the species of the animal. The space between the alveolated surface of a disc and the smooth surface of the one behind it is entirely occupied by connective tissue containing and supporting blood-vessels and nerves, all of which go to form what M. Robin calls the "*cloison*." Each arteriole as it enters the *cloison* from the longitudinal septum divides into capillary branches, all of which tend forward and terminate in loops, which occupy the alveoli on the posterior face of each disc. The nerves, which enter the *cloison* in the same way as the arteries, at once separate from them by dividing into branches, which tend backward, to be distributed to the smooth surface of each disc. It thus appears that each disc receives its blood-supply from behind, and its nerve-supply from the front; and the separation of nerves and blood-vessels is so complete that, while in the connective tissue filling the alveoli there are no nerves, in the rich plexus of nerves covering the anterior smooth surface there are no capillaries. The substance of the disc is, according to Robin, not entered either by capillaries or nerves, and consequently their terminations never come nearer to each other than the distance between the deepest alveoli and the smooth anterior surface of the disc (one-fifth millimetre). The medullated nerves he describes as forming a plexus over the anterior surface of the discs. Each medullated fibre ends by branching into two, three, or even four filaments, and these again divide, at the same time losing their medullary sheaths, and finally their nucleated sheaths, after which they are continued as axis-cylinders. Many of these terminal branches are connected close to the surface of the disc with "nucleated multipolar

cells of irregular form." From these cells fibrils two-one-thousandths to three-one-thousandths of a millimetre in diameter tend toward the surface of the disc, dividing repeatedly, so that in longitudinal sections of the organ these nervous terminations present an appearance described by Robin as resembling bunches of root-hairs (*chevelu radiculaire extrême ment riche*). On arriving at the surface of the disc each fibre terminates in a pyramidal or conical body, from four to five thousandths of a millimetre in length, the base of which is applied to the disc. The plexus of nerves, with its terminations, separates very easily from the disc, and presents in surface-view a finely-granulated appearance, with minute perforations here and there, the granules representing the terminal pyramids. On focusing below the surface, the field appears to be beset with minute points, which are the optical sections of the terminal fibres.

The description, of which a summary has just been given, we find to be correct as regards almost all the points to which it relates. The only statements which we are disposed to question are, first, the description of compartments, which are not lozenge-shaped, but, as a rule, oblong and rectangular in section, and, second, those which relate to the multipolar cells in the nervous plexus and to the pyramidal bodies in which M. Robin believed that the nerve-fibrils terminated. To these points we shall recur in giving an account of our own observations upon the structure of the organ.

The minute structure of the electric organ was investigated in *Raia clavata*, by Prof. Max Schultze, in 1858. His attention was directed almost exclusively to the mode of termination of the nerves. He considers that the disc, the structure of which he minutely describes, owes its existence to a coalescence (*verschmeltzung*) of the terminations of the nerves, of which its intercellular substance is a direct continuation He describes the nerve-endings as constituting a fine net-work, which in the disc is transformed into a solid nervous mass, part of which can be split into laminæ, the remainder consisting of finely-granular substance inclosing nucleated cells. The chief foundation for this view of the morphological import of the disc seems to be a peculiar microchemical reaction common to the disc and nerves. Both are colored red by sulphuric acid and sugar.

M. Robin's experiments on the electric properties of the organ are of importance only in so far as they afforded for the first time experimental proof that its function is in accordance with its structure. It had previously been designated by du Bois-Reymond as "pseudo-electric," but in consideration of Robin's investigation he now proposes to distinguish it from the electric organs of the torpedo, gymnotus, etc., by the term "incomplete" (*unvollkommen*). It is, however, difficult to see that the new word is better fitted than the old one to express its character, for the organ, though small, is as perfect in structure and function as that of the gymnotus or the torpedo.

Histological Observations Made by Professors Sanderson and Gotch.—The relations of the electric organ to surrounding parts can be best understood from the engraving (Fig. 5), which represents in outline a transverse section of the tail, where it occupies most space. It is seen that its surface is mapped out into polygonal areas by the cut edges of the longitudinal septa, and that these radiate more or less distinctly from the obtuse angle on the median side of the section, which corresponds to the line of attachment along which the vessels and nerves enter. It is also noticeable that the external areas are arranged concentrically around the central ones.

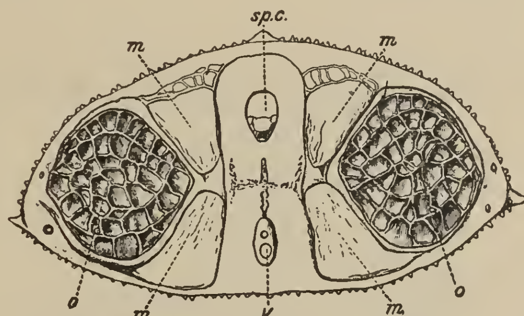

FIG. 5.—TRANSVERSE SECTION OF TAIL OF LARGE SKATE (RAIA BATIS).
Actual size.
sp.c., spinal canal; *v*, vascular canal containing caudal artery and vein; *m*, muscles; *o*, electric organ.

In Fig. 6 the engraver has given the general effect of a photograph of a longitudinal frontal section, as seen under the microscope with a low power. It serves to show that the organ consists of spindle-shaped tubes, imperfectly divided into loculi placed one above the other, and each holding a disc. These tubes are so arranged that their axes are either parallel or very slightly diverge backward. The discs are, so to speak, suspended by the connective tissue which supports the blood-vessels. As has already been stated, the arterioles follow, in the first instance, the longitudinal septa by which the tubes are separated from each other. From the septa terminal arterioles pass transversely—*i.e.*, at right angles to the axis of each tube—into the spaces between each two adjoining discs, occupying a position about half-way between their two opposed surfaces. The description of their distribution, which we have given from M. Robin's memoir, need not be repeated. Both arteries and veins are accompanied by connective tissue, which in the horizontal part of their course is of sufficient strength to deserve the name of a lamina, although it is distinguished from the rest of the connective tissue, which occupies the space between the discs merely by the closer arrangement of its fibres.

On the caudal side of each of these laminæ of connective tissue and blood-vessels, and consequently between it and the disc behind it, there

exists a plexus of medullated nerves; the relations and mode of termination of which can be best seen in sections of the frozen, perfectly-fresh organ, which, after having been first placed in normal salt solution, are treated on a slide with 1-per-cent. solution of warm osmic acid. In such sections what we propose to call the *nervous lamina* is seen to be attached to the nucleated membrane which covers the anterior surface of the disc by a well-defined border. The terminal fibres which end abruptly at this border can usually be traced back to a bifurcation of the characteristic form shown, and the nerve-fibre from which the two prongs spring to a medullated nerve in the plexus already referred to. We are not able to confirm M. Robin's notion as to the nervous nature of the

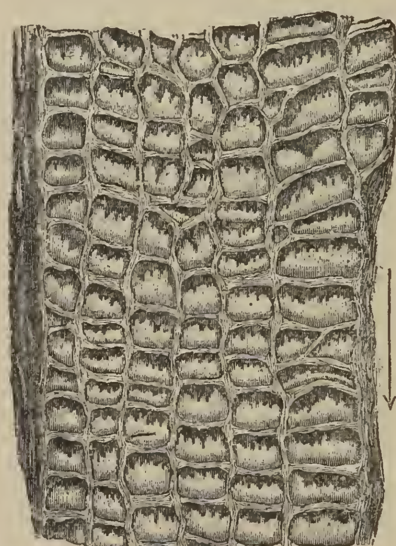

FIG. 6.—LONGITUDINAL SECTION OF UPPER PART OF ORGAN AS SEEN UNDER LOW POWER (RAIA BATIS). The arrow indicates the direction of the shock.

branched (or multipolar) cells, which are in relation with the terminal ramifications of the nerves. Some of these cells unquestionably belong to the nucleated sheaths of the nerve-fibres; others are probably connective-tissue elements. As to the mode of ending of the ultimate fibrils we are uncertain. In sections of the organ hardened in chromic acid the border of the nervous lamina exhibits a beaded appearance of very great regularity, and it can be seen that each of these beads has a terminal fibril leading to it; but no such structure can be made out in osmic-acid preparations. Whether this appearance means that the minute terminal fibrils end in the way described by M. Robin, or give off even finer branches, we are unable to state. All that we have been able to observe with certainty is that they can be traced up to, but not beyond,

the surface of the disc, and that their direction is perpendicular to its surface.

The morphological meaning of the structure described in the preceding paragraphs can only be understood by referring to its development, which has been lately made the subject of study by Professor Ewart. It is sufficient to say that, although each disc occupies the place of an undivided muscular fibre, it belongs histologically to the nervous system, not to the muscular. It is, in short, *sui generis*, and cannot be identified with anything excepting the organs of similar function found in other fish. That in several important particulars it resembles a muscular

FIG. 7.

nerve-ending or muscle-plate cannot be questioned. Just as the ramifications of the nerve terminate in the end-plate without being part of it, so the myriad fibres of the nerve-lamina end in the nucleated layer which in the adult organ, but much more strikingly in earlier stages of its development, corresponds in structure with the granular nucleated substance. Physiologically the two correspond; for just as at the instant that a muscular nerve is excited the end-plates become positive to the nerve itself, so here excitation of an electric organ determines an instantaneous change in the same direction at the surface of every disc. But these considerations do not afford sufficient ground for any conclu-

sion as to the analogy between the "electric plate" and the "motor end-plate." On this point we would defer expressing an opinion until we have the opportunity of acquiring more exact information than we as yet possess as to certain of the physiological relations of the former, and particularly the influence of curare, since it is well known that in the case of the torpedo the electric organ is not affected by that poison, even though all the muscular nerve-endings are completely paralyzed.

Method of Experiment.—The skate was secured with its ventral surface downward on a board shaped like a racquet, the tail projecting along the narrow handle. The board was then plunged in a tub of sea-water, the tail being left exposed. The apparatus used to give, indicate, and record electric currents were the same as those usually employed in muscle-nerve physiology, including the capillary electrometer.

As a result of their experiments, Professors Burdon-Sanderson and Gotch draw the following conclusions, which are in harmony with experiments made on the torpedo:—

Conclusions.—1. In *Raia batis* and *clavata* an electric organ exists which corresponds in structure and function with other electric organs in fishes. It possesses the fundamental endowment by which electric organs are distinguished from other electro-motive and excitable structures, namely, that its electro-motive elements are arranged in series after the manner of a voltaic pile, so that the effects of excitation increase proportionally to the number of elements in series which are brought into action. The maximum electro-motive force of the shock—*i.e.*, the electro-motive force corresponding to one centimetre length of organ—we have roughly estimated to be about half a volt. In the torpedo it is probably ten times as much. 2. The natural discharge or shock of the electric organ consists of a succession of electric disturbances, in each of which the distal (caudal) end becomes positive to the proximal (cephalic) end. 3. A similar discharge can be evoked by exciting the spinal cord by a single induction shock, provided that the part excited is at some distance from the organ. 4. Similar excitation of the part of the cord from which the organ receives its nerves is followed at an interval of about a hundredth of a second by an "excitatory response" of extremely short duration (two- to three- hundredths of a second); this effect, of which the direction is always normal, must be regarded as analogous to the excitatory variation of a nerve when subjected to a single instantaneous excitation. 5. The passage of an induction shock through the prepared organ is followed, after an interval of about five-thousandths of a second, by a similar "excitatory response," the direction of which is always normal, whatever may be the direction of the exciting induction current. 6. The excitatory state is not propagated in the electric organ, but is limited to the part to which the excited nerves are distributed, whether the seat of excitation be the spinal cord or the organ itself. 7. In the uninjured organ there may or

may not be a difference of potential between the cutaneous surfaces covering the upper and lower ends of the organ respectively. If a difference exist it is usually in the normal direction, *i.e.*, the distal end is positive to the proximal. In the prepared organ such a difference almost always exists, and this is suddenly augmented, if present, or brought into existence, if absent, by any injury of the surface of the organ, and more particularly by momentary exposure of it to a high temperature. The effect so produced rapidly subsides, but a residue of it remains, and may last for some time. 8. When the organ is divided transversely the injured end is not thereby rendered negative to the uninjured. 9. When an induction current of sufficient strength is led through the organ it produces, in addition to the excitatory response, an after-effect which resembles, both in its constant normal direction and in its time relations, the effect produced by injury, but is of relatively small electro-motive force. It is produced by currents in either direction, but is stronger when the direction of the induction current is normal. 10. A similar excitatory after-effect, accompanied by polarization, follows the passage of a voltaic current of sufficient strength and suitable duration. 11. A similar after-effect follows the natural shock as well as the "excitatory response." We understand this to mean that just as by the action of an external current the organ is brought into a state of sub-excitation, manifesting itself in a temporary increase of the normal difference of potential between its ends, so the current of the shock or of the excitatory response produces a similar sub-excitation. There, as in the skate, we have a normal discharge of central origin; an "excitatory response" due to excitation of the nerves of the electric organ; an "organ-current" capable of being brought into existence or augmented by injury of the surface; after-effects, physiological or merely physical, *i.e.*, due to polarization; and, finally, all physiological electro-motive effects, whether they come under the designation of shock, of excitatory response, of organ-current, or of after-effect, in one and the same normal direction.

SECOND RESEARCH.

A second investigation was undertaken by the same physiologists, with a view of answering certain questions, more especially in regard to the normal reflex process by which the electric organ is discharged, and the measurement of the electro-motive force of the response of the organ to a single excitation. The results of this research will be found in the following summary of the investigators themselves:—

Conclusions.—1. Spontaneous discharge of the electric organ of the skate has not, so far as we know, been observed. A reflex discharge can always be induced by mechanical stimulation of the skin, particularly that of the dorsal surface. 2. The afferent paths by which the reflex is excited are contained, for the most part, in the spinal nerves. Although

discharges follow electric excitation of certain branches of the trigeminus, they can be evoked reflexly after all the cranial nerves have been divided. 3. The reflex discharge is always discontinuous,—*i.e.*, it consists of a group of two or more single electric effects, which follow each other with a frequency of from eight to twenty-five per second. If the stimulation is prolonged, this primary group may be succeeded by others of a similar character. 4. A reflex centre is situated in the optic lobes. Electric stimulation of the dorsal surface of these lobes produces while it lasts a discontinuous discharge of the same character as the primary reflex discharge. 5. The discharge goes on after the excitation has ceased, manifesting itself either by prolongation of the primary effect or by the recurrence at intervals of secondary effects similar to the primary. 6. Electric stimulation of the anterior region of the cord after it has been separated from the bulb also evokes a discontinuous discharge, which lasts as long as the excitation. It is followed by effects of the same kind as those which follow excitation of the optic lobes, but these are less intense and of less duration. This part of the cord must therefore be capable of automatic action, although there is no evidence that it can be excited reflexly. 7. Each disc of the electric organ is capable of developing, during the state of excitation evoked by a single induction shock, an electro-motive force of over 0.02 Daniell. The sartorius muscle of the frog (as we have found in our own experiments) is capable, when excited by a single induction shock led through its nerve, of developing an electro-motive force of 0.026 Daniell. The number of nerve-fibres distributed to the disc is certainly not less than that of the constituent fibres of the nerve of the sartorius. There is therefore no reason to regard the electric activity of a disc as extraordinary as compared with a muscle of similar innervation.

The relatively large electro-motive force which the organ as a whole is able to develop is attributable (1) to the large number of discs of which it consists, (2) to their being arranged in pile, and (3) to the nervous arrangements by virtue of which they are enabled to act simultaneously.

Addendum.—Since the foregoing pages passed into the printer's hands a most interesting paper on the origin of the electric nerves of the torpedo, gymnotus, mormyrus, and malapterurus, by Professor Gustav Fritsch, of Berlin, has appeared in *Nature*, vol. xlvii, No. 12. The reader who is especially interested in this part of the subject will do well to refer to this paper, which is admirably illustrated by photographs from nature.

The writer gives here a brief outline of the paper, without comment :—

Electric organs are of muscular origin. This is well seen in a cross-section of the tail of the mormyrus, in which instead of muscles one

finds electric tissue, only the longitudinal tendons passing outside the electric organs from muscles placed anteriorly. Again, in the electric eel (*Gymnotus electricus*) of America a similar section shows that a part of the muscle-tissue is changed into electric organs, the rest remaining unchanged. In the electric skates the electric organs are developed from muscles that originally belong to the branchial arches and the arch of the lower jaw. In all cases in electric fishes the impulses that pass along the nerves and call forth the electric discharge proceed from ganglion-cells. In the torpedo the ganglion-cells are collected in a bean-shaped mass in the medulla, forming an electric lobe, and estimated at about fifty-four thousand. In connection with these an equal number of nerve-fibres have been found. In the electric eel the electric cells form a continuous column in the spinal cord,—long and slender, and amounting probably to sixty thousand. The arrangement in the mormyrus is similar. The protoplasmic processes of the cells must have a conducting function, a remark which applies probably also to all ganglion-cells. In the electric fish of the Nile (*Malapterurus electricus*) muscular tissue is abundant and the electric organ seems to have been developed from the skin. In these the electric current passes through the body in a direction opposite to that in other electric fishes. The innumerable nerve-branches are all derived from *two* electric nerve-fibres, the structure of which is very suggestive of an electric cable, and leading inward each to a single ganglion-cell. This is of great size, having no real axis-cylinder arising from it, but, in place of it, branched protoplasmic processes join and form a kind of perforated plate beneath the cell, from which the nerve-fibre starts. Since it is clear that ganglion-cells are the real centres concerned in all kinds of electric fishes, it seems reasonable to believe that in other animals they are not merely trophic, but distinctly motor. The great value of such investigations as these is owing to the light they throw on nervous processes generally, and on the remarkable development effected by organic evolution.

BIBLIOGRAPHY.

Instead of enumerating all the original sources of information in this article, the reader is referred to "Biological Memoirs," edited by Professor Burdon-Sanderson, and to the Journal of Physiology, vols. ix and x, in which will be found a very elaborate list of references.

STATIC ELECTRICITY AND MAGNETISM.

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THE state of transition through which electrical science is at present passing renders it difficult to treat the subject with that degree of lucidity which the logical mind demands. With the phraseology and, to a certain extent, the conceptions of the older theories, we are gradually rising to generalizations which tend more and more to give a new meaning to all electrical phenomena. That meaning is not yet clear enough, however, to enable us to put aside the older views and to start afresh with new terms and new definitions. We have still to accommodate ourselves to the imperfections of a transitional indefiniteness, and to employ language which the passing months are rendering obsolete. As long, however, as we endeavor to import into the older phraseology a meaning more in keeping with the results of modern discoveries, we cannot go far astray. We may still, for instance, use Franklin's, or the dual theory of electricity, if we apply to them the corrections furnished by modern science. The chief exponent of these modern views is Prof. Oliver Lodge, whose treatment of the subject will occupy our attention in the earlier pages, and will, I hope, be the means of placing the phenomena of electro-statics in a somewhat clearer light.

The ethereal theory of electricity presupposes the existence of a perfectly subtle, continuous, incompressible substance pervading all space and penetrating between the molecules of all ordinary matter which are imbedded in it and connected to one another by its means; and we must regard it as the one universal medium by which all actions between bodies are carried on. This, then, is its function: "To act as the transmitter of motion and energy." We have long known this substance or fluid as *the ether*, and to its vibrations we are indebted for the light of our planet. Professor Hertz, of Bonn, has conclusively shown that these vibrations are electrical vibrations, but electrical vibrations by reason of their short wave-length appealing to a sense-organ which we possess. We have no sense-organ for ordinary electrical waves; their length is such that the retina cannot take them up. Professor Hertz has, however, by a stroke of genius, made these electrical vibrations visible to us by simply shortening their wave-length, and has shown, moreover, that they obey all the laws of optics,—can be reflected, refracted, etc., and that they travel at exactly the same rate that light travels.

So electricity has annexed the whole domain of optics. Now, vibrations of light which we know the ether transmits must be transmitted by

something possessing rigidity; rigidity means active resistance to shearing stress, *i.e.*, to alteration in shape; it is called *elasticity* of *figure.* It is by the possession of rigidity that a solid differs from a fluid. For a body to transmit vibrations at all it must possess inertia. (Inertia is defined as ratio of force to acceleration. Transverse vibrations can only be transmitted by a body possessing rigidity; all matter possesses inertia, but fluids only possess volume elasticity, and, accordingly, can only transmit *longitudinal* vibrations.) Light consists of transverse vibrations; air and water have no rigidity, yet they are transparent, *i.e.*, transmit transverse vibrations; hence it must be the ether inside them which really conveys the motion, and ether must have properties which, if it were ordinary matter, we should style "inertia and rigidity."

This electrical ocean, in which we and everything else are immersed, has been likened by Sir William Thomson to a mass of jelly which allows all bodies to pass through it without friction, which is perfectly fluid for steady forces, but rigid for infinitesimal vibrations, and, as water is contained in jelly, so is electricity contained in the ether. Electricity thus becomes a mode or manifestation of the ether, as heat is a mode of motion of material particles. Conductors are bodies which allow electricity to flow through them,—when immersed in such a medium, they become cavities or channels. But electricity is entangled in such a medium, and through this it cannot penetrate without violence or disruption. Yet bodies can move freely through it. The electricity is alone entangled. The cavities, cracks, or spongy bodies, which are pervious, but with more or less frictional resistance to the flow of liquids through them, are the *conductors.* The insulators or dielectrics are like elastic or impervious partitions, but yielding masses, subject to strains when electricity is moved. As a general definition it may be said that *all transparent substances* (not fluids) *are insulators*, and that all opaque bodies are conductors.

By insulating, *i.e.*, supporting on glass stems such opaque bodies as brass spheres or cylinders, and connecting them by copper wire, you have so many cavities and tubes in an otherwise "continuous elastic and impervious medium, which surrounds us and them, and extends throughout space wherever *conductors* are not." But we must remember that all—cavities as well as the rest of the medium—are full of the universal fluid. We see that if matter were perfectly conducting, electrostatics would be impossible. It is by pumping electricity from one place to another, at the same time straining the elastic walls between conductors, that we make static electricity manifest. There are different ways of making the presence of electricity manifest: 1. By mechanical means, as friction, pressure, concussion, cleavage, or mere contact. The latter seems the essential element. This includes the domain of static, frictional, or Franklinic electricity. 2. By chemical means; this includes voltaic, galvanic, or dynamic electricity. 3. By means of heat and mag-

netism; this includes thermo-electricity and magneto-electricity. It must be remembered that the electricity made manifest by these different methods is exactly the same electricity, and differs merely in intensity and quantity.

Whether the ethereal theory of electricity will satisfy all the requirements of a scientific age or not, I think we can, without hesitation, accept the fact that electricity behaves exactly as an incompressible and inextensible fluid would behave. It is not meant for a moment that it is a fluid in the ordinary sense of the word, but that the different methods enumerated are merely forces applied in moving it freely through conductors and straining insulators or dielectrics, and, if the force applied is strong enough, bursting the walls confining it.

Electricity always flows in a closed circuit; it is of the utmost importance to always remember this. A cable across the Atlantic is like an India-rubber tube already full of water, with both ends opening into the common ocean at their destination. A force-pump may be used to force a certain quantity of water out at one end, but just exactly the same quantity enters at the other end; so we see that the ocean is equally as much a part of the circuit as the tube. Electricity obeys exactly the same laws; the same quantity of electricity enters at one as was forced out at the other end.

If we place a flannel cap to which a silk thread is attached over one end of a stout rod of vulcanite (both having been previously warmed), rub the cap around the rod a few times, then remove the cap and hold it near a positively-charged pith-ball pendulum, the pith ball is repulsed; the flannel is therefore charged positively (as we know, like charges repel and unlike charges attract). Present the rod to the pith ball, violent attraction ensues; therefore the rod is negatively electrified. Now replace the cap and rub again; without removing the cap, hold both to an uncharged pith-ball pendulum, and neither divergence nor attraction ensues. Thus we conclusively prove that (1) positive and negative electrifications are generated together; in fact, one kind of electrification is never produced without the other. 2. The positive electrification is exactly equal in amount to the negative. So that no electricity has been actually generated; it has been merely moved from one body to another, or we might say that electrifying a body positively is adding something to it; then electrifying it negatively to the same extent will simply mean taking an equal amount of that something from it. We have seen that when the vulcanite rod was rubbed there was a transfer of something from one to the other; in separating them a short distance there is a force exerted across the air or dielectric tending to bring them together. Faraday would have said that they are connected by lines of force, and that these lines tend to shorten and thus bring them together. At present we say that the medium between them is in a state of strain.

In an ordinary electrical machine we rub glass with some other substance, such as leather. The rubbing in this case has no special action in the transfer of the electricity; it is not the *cause* of the electricity in the same sense as it is the cause of heat. It is most likely that simple contact between dissimilar substances is the essential condition. Friction brings into close contact numerous particles of the two bodies; it also cleans, warms, and dries the surfaces; these all favor insulation, and so prevent the escape of electricity. Practically, to obtain marked electrical effects from the contact of two insulators, they must be rubbed together. When two conductors are brought together, such as zinc and copper, they are charged with electricity of opposite sign. Friction here neither increases nor diminishes the charge; as metals are conductors, the charge is instantly distributed. This charge is much more feeble than when two insulators are rubbed together. When the glass is rubbed by the leather, a transfer of electricity is effected,—the electricity on the rubber is conveyed to the earth; that on the glass accumulates on an insulated conductor, and, as it is surrounded by an insulating atmosphere, it does not escape. The electrical machine here acts exactly like a pump attached to two bodies, respectively, driving some electricity from one to the other, giving one a positive charge and the other a precisely equal negative charge. One body is the earth and the charge therefore makes little difference to it. The act of charging a conductor is analogous to pumping water into an elastic bag, or, better, into a cavity in the elastic medium that we have previously been considering; the medium's thick walls, extending in all directions, need great pressure to strain them. We now come to the most important principle in static electricity.

The Seat of Charge of Electricity is the Outer Surface of Conductors.—Consider two cavities in this elastic medium, or, better, draw them on a piece of paper and "consider fluid pumped from one to another, and you will see the charge (*i.e.*, the excess or defect of fluid) resides on the outside. If the fluid is exactly incompressible, not the least extra quantity will be squeezed by the pressure into the space originally occupied by the cavity. You may show that when both cavities are similarly charged the medium is so strained that they tend to be forced apart; whereas, when one is distended and the other is contracted they tend to approach. Further, you may consider two cavities side by side, pump fluid into (or out of) one only, and watch the effect on the other. You will thus see the phenomena of induction,—the near side of the second cavity becoming oppositely charged (*i.e.*, the walls encroaching on the cavity), the far side similarly charged (the cavity encroaching on the walls), and the pressure on the fluid in the cavity being increased or diminished in correspondence with the rise or fall of pressure in the inducing cavity."

If we take a cylindrical glass jar and coat it, both inside and outside, to within two or three inches of the top, with tin-foil, we make a

Leyden jar. Place such a jar on an insulating stand and connect either coating, by means of a chain, to the conductor of an electrical machine, and work the machine for a short time. As the coating in connection with the machine has received a charge, we should expect to get a spark if we connected the coatings together, say, with the hand. If we get a spark at all, it will be an extremely feeble one. Now let us connect as before, say, the inner coating to the conductor of the machine and the outer coating to the earth, by means of a chain or the hand. If we turn the machine as many times as before, a very strong spark will be obtained by presenting a finger to the inner coating, thereby connecting it through the experimenter's body and the earth with the outer coating. All electrical charging of bodies is exactly analogous to the charging of a Leyden jar; so we have here the key to the whole problem of electrostatics. We cannot charge one body alone, we cannot charge one coating of a Leyden jar alone; an exactly equal charge must be given to the other coating. When we charge an insulated conductor in a room, the walls and floor of such room represent the outer coating, the inner coating being the conductor; the air, with its contained ether, the dielectric, and is analogous to the glass in the jar. We have seen that we cannot charge an insulated Leyden jar. If we had a pith ball attached to each coating, both would rise equally and simultaneously when the attempt is made to charge the jar. Their levels or potentials would be equal, therefore no spark would pass. In fact, we have been trying to force an absolutely incompressible fluid into a space already full of such fluid. When we connect the outer coating of the jar to the earth we allow of the escape of just so much electricity as we pump in from the electrical machine; so, to charge a Leyden jar, for every spark we give the inner coating we must take an equal spark from the outer coating. This may be made plainer by thinking of the coatings of the jar as two India-rubber tubes (conductors) and the (dielectric) glass as an electric diaphragm uniting the tubes. The tubes are filled with water, and one end connected to a pump; we now close the end farthest from the pump by a second sheet of India rubber. If we then work the pump, the elastic diaphragm (dielectric), which does not allow water to pass, is stretched slightly, moving the water a little forward on the other side of the diaphragm, and thus to a slight extent stretching the elastic covering on the farther side of the tube. If the pump is removed, there is a small recoil of the elastic, and any extra water that has been forced in escapes again from the end of the tube which was connected with the pump. This represents the small spark from the charged insulated Leyden jar.

In the second experiment the outer coating of the jar was in connection with the earth. Therefore we must now remove the elastic covering from the farther end of the tube, and allow both ends to dip into a tank with which the pump is also in connection. It is well here to

remember that electricity always flows in a closed circuit. When the pump attached to the near end of the tube is now worked, water will be forced into the tube representing the inner coating; at the same time the diaphragm is stretched, and exactly the same quantity of water will be forced from the tube representing the outer coating. The pump may be worked so as to strain the diaphragm (dielectric) very greatly or even to burst it. If the force (pump) be now removed, we have a quick recoil of the diaphragm (dielectric), the extra quantity of water is again forced out at the pump end of the tube, the equilibrium being adjusted by the water of the tank entering the far end of the tube. In this experiment the quantity of water forced in has been much greater, the diaphragm has been stretched to a much greater extent, and the recoil (spark) has been more powerful. In the case of the jar, given a sufficiently-powerful machine the electrification may be increased until it either overflows or discharges through the glass, which would be broken in the process. If the jar is properly constructed, the tin-foil will be taken up so near the edge that the discharge, when it takes place, will occur through the air, instead of the glass, thus saving the jar.

These experiments can be also made to illustrate the process of induction. If we bring a charged body near an insulated conductor, we drive electricity of like sign to the far side of the conductor, and electricity of an opposite sign we attract to the near side. If we now connect the far side of such conductor to the earth, by means of the finger or a wire, we allow this electricity to escape, and we have two bodies oppositely charged, separated by a dielectric. The same thing occurs in the Leyden jar and its analogue, the India-rubber tube. We found that when the jar was insulated it refused to charge, but when we connected the outer coating with the earth we had the two equal and opposite charges separated by the dielectric (glass). It has been conclusively proved, by examining the glass under such conditions by means of polarized light, that it is in a condition of strain.

We have looked at electricity in the foregoing from Franklin's point of view, *i.e.*, that there was one electricity. A positive charge meant an excess, a negative charge meant a deficiency, of the universal fluid. This view seems to fit in well with the examples given of pumping an incompressible fluid into elastic cavities with thick walls, spongy bodies, and elastic bags, and thus stretching the walls. There is an obvious defect in the analogy, as the volume of the cavity is increased or diminished when we pump fluid into or out of it. We know—when we charge a conductor—that there is no change of volume in the conductor. So we have to map out, as it were, and think of the original space inside the cavity in its unchanged condition, already full of the incompressible fluid, as the true conductor. You cannot fill it any fuller, therefore the excess or defect of fluid would be on the outside, *i.e.*, in the dielectric. This might be obviated by viewing electricity as composed of two separate

entities, and not looking at negative electricity as mere negation. There are many reasons for thinking that this represents the true state of the case,—the facts of electrolysis—the two opposite processions of atoms—conveying their charges of positive and negative electricity in an electrolyte. The electrical flow in opposite directions on the Holtz machine, the strain phenomena in a dielectric, would be explained by the molecules in such dielectric being stretched by their oppositely-charged atoms, the tearing asunder of the molecules as being disruptive discharge, which is undoubtedly of an electrolytic nature ; so we would have, as in an electrolyte, two opposite processions of atoms carrying their electric charges.

Static Electricity, or Electricity at Rest, or, rather, in a State of Strain.

In the previous pages I have endeavored broadly to give a general view of the whole subject of static electricity, utilizing the ethereal electrical theory, as propounded by Professor Lodge, as a means of adding more definiteness and reality, than is given in most text-books, to electrical phenomena. We must now endeavor to treat this subject more methodically ; but I hope the general view already given will be a material aid to a more perfect understanding not only of this branch of electrical science, but also of its action on the human body.

CONDUCTORS, INSULATORS, AND ELECTRODES.

We have seen that certain bodies allow electricity to pass through them and are called *conductors.* Bodies which do not allow electricity, or allow it with difficulty, to pass through them are called insulators, or dielectrics. The metals, charcoal, water, solutions, and moist bodies, such as the earth, are conductors. Air, whether damp or dry, and all gases, including dry steam ; most kinds of glass, sulphur, India rubber, vulcanite, shellac, gutta-percha, and other resins ; some oils, dry silk, and cotton, are insulators. Wood, stone, and flax are imperfect insulators. The difference between conductors and insulators is one of degree only ; all solids and liquids resist the passage of electricity to some extent, and none prevent that passage entirely.

The insulator plays an important rôle in the application of static electricity. If the patient is not well insulated there is a great waste of electricity and the power of the machine may be quite neutralized. The most perfect insulator is a platform of glass having glass supports about twelve inches in length.

The electrodes required need not be many ; they should include a large and small brass ball, a metal point, a wooden point, and a wooden or ivory ball. A metal-cap electrode for the head is a good means of producing the souffle. The ear-electrode is made of vulcanite formed into the shape of an ear-speculum and pierced with a brass wire. In applying this

to the ears care must be taken that the sparks to be drawn should be very small; a wooden point or ball should be used in preference to metal.

MODES OF PRODUCING AN ELECTRIC CHARGE

We have seen that rubbing two different substances together is the usual method of producing an electric charge. Each substance in the following list usually becomes positively electrified when rubbed or pressed against any of the substances placed after it, but negatively electrified when rubbed or pressed against any substance preceding it in the list. We obtain the most marked effects by using pairs of substances which are far apart in the list: cats' fur, glass, ivory, silk, the hand, wood, sulphur, flannel, cotton, shellac, caoutchouc, resin, gutta-percha, metals, and gun-cotton.

Two conductors in contact, whether solid or liquid, charge one another with electricity of opposite sign. Friction between the metals neither increases nor diminishes the charge. As metals are conductors, the electricity is instantly distributed over them. When insulators such as glass or resin are pressed or rubbed together, only those parts which come into actual contact are at first electrified. The electricity in time spreads farther because the insulation is imperfect. Two insulators which have been rubbed together retain their charges unmodified for some time after their separation; this is not the case with conductors.

FORCE BETWEEN ELECTRIC CHARGES.

Bodies charged with electricity of the same kind repel one another by virtue of their charge; bodies charged with opposite electricity attract one another. The fluid with which any body is charged cannot leave the body, being retained by the surrounding dielectric; any force acting on the electric fluid acts, therefore, on the dielectric. Equal charges under equal conditions produce equal forces. We thus have the means of ascertaining whether two bodies—say, spheres of equal diameter—are equally charged with electricity; to do this we have only to observe whether, at equal distances, they exert equal forces on a third body charged with electricity. Means exist by which equal charges can be added so as to accumulate on one conductor, and we find by experiment that two equal quantities of the same sign, when thus added, attract or repel a given charge, on another body, with twice the force which was exerted by each singly, when in the same place; also that two equal quantities of opposite sign neutralize one another so as, after their combination, to exert no force. These facts enable us, independently of all hypothesis as to the nature of electricity, to treat an electric charge as a measurable *quantity*. Instruments for numerically measuring or comparing the forces due to various charges of electricity are called *electrometers*. Instruments which simply indicate the existence of a force due to a charge are called

electroscopes. The unit quantity of electricity is that which repels another equal quantity at a unit distance with unit force.

DISTRIBUTION OF ELECTRICITY ON CONDUCTORS.

Electricity, as we have had occasion before to emphasize, resides on the surface of conductors. That this is absolutely true the well-known experiment of Cavendish or Biot proves. If an insulated metal ball be strongly charged with electricity and we place two hemispherical metal envelopes furnished with glass handles on the sphere so as to envelop it, after contact with the sphere, carefully remove the hemispheres, and by means of the glass handles bring them near an uncharged gold-leaf electroscope, in each case the leaves diverge; now bring the ball near the electroscope, the leaves do not diverge, although the ball originally received the charge. We see that the charge has passed from the surface of the ball to that of the covers. This is what we should expect if we recall the experiment with the cavities in the elastic medium; "electricity being exactly incompressible, not the least extra quantity will be squeezed by pressure into the space originally occupied by the cavity." Even if the conductor be hollow and the charge be given to the inside, the result is precisely the same; it immediately flows to and over the surface. Many experiments might be adduced to prove this law.

Faraday had a cube-shaped room constructed and rendered a free conductor of electricity in every part. This chamber was insulated in the lecture-room at the Royal Institution. He went into this cube and lived in it, "used lighted candles, electrometers, and all other tests of electricity, and could not find the least influence upon them or indication of anything particular given by them, though all the time the outside of the cube was powerfully charged, and large sparks and brushes were darting off from every part of its outer surface." Mr. Boys has shown, by means of two soap-bubbles, one inside the other, that electricity did not penetrate the wall of the outer bubble, a soap-bubble being a conductor of electricity.

REDISTRIBUTION AND SUBDIVISION OF CHARGES.

If an insulated conductor is charged so as to be unaffected by other electrified bodies, and any portion of that charge be removed, the remaining electrification will distribute itself over the surface in a manner similar to the distribution of the original charge. Suppose, for example, that we have several insulated metallic spheres of equal size, one of them being charged with a certain quantity of electricity and the others uncharged. If one of the latter be brought in contact with the charged sphere it will receive half the charge; if on separating the spheres either be brought in contact with another uncharged sphere, it will receive half *its* charge, *i.e.*, one-fourth of the original charge. The distribution in each case will be uniform.

POTENTIAL.

The quantity of electricity in an electric charge is a conception analogous to that of a quantity of material fluid. So the idea of electrical potential is analogous to that of level in a body of water; that is, level as indicating a condition by which gravitating matter, such as water, can do work in descending to a lower level. The electrical potential of a conductor is that condition of the conductor in virtue of which the electricity tends to pass from the conductor to the earth, and in so passing do work,—the earth being considered at zero potential.

DENSITY.

The density of a charge at any point is the charge per unit area at that point. The density of a charge is uniform on all conducting spheres when they are unaffected by the proximity of other conductors. When the thickness of the dielectric between two conductors is variable the density of charges induced between them tends to be greater the nearer they approach. The density of any charge tends to be greater at all projecting edges or points. The electricity on any small area of an electrified surface is acted on by a force normal to that surface. This force tends to stretch the conductor outward, or tear off a part of its surface, and is called the electric *stress*, or tension, at that part of the surface. Stress or tension is measured in units of force per unit of area, and is proportional to the square of the density on the element of surface.

ELECTRICAL CAPACITY.

If we take two unequal-sized vessels and fill them with water, the quantity of water they will hold, of course, depends on their size or capacity. Similarly, if we take two insulated conductors of the same shape, but of different size, and electrify them, the large one must have a greater charge than the small one to electrify it to the same potential, —*i.e.*, the large one has a greater electrical capacity than the small one. Thus, the potential of a conductor depends both upon its charge and its capacity; in fact, if C equals the capacity of a conductor, Q the charge or quantity of electricity, and V the potential, then C equals $\frac{Q}{V}$.

CONVECTION—SPARKS; POINTS; SILENT DISCHARGE; BRUSH.

Convection occurs when electricity is conveyed from one place to another by small particles of matter, which they carry as a charge. A charged conductor can be discharged by convection if steam or spray be blown to or from it; each globule of water leaving the conductor carries away a charge of electricity. When two conductors of different potentials are brought close together, one or more sparks will pass between them. The *spark* consists of white-hot matter electrically charged. The disruption of this matter from the body is caused by the breaking down

of the strain in the dielectric; the heat and light observed are due to the mechanical action of the disruption,—as when a spark is struck by a steel upon flint, the spark is not electricity. In a conductor charged to a high potential the electricity escapes from any sharp *points* or edges. The action is one of convection by a stream of particles producing an actual current in the air, and is due to the stress at the points or edges. When the action is unaccompanied by noise or light, it is called a *silent discharge;* when accompanied by noise or light, the term *brush* is applied to the phenomenon.

As we have to deal with the human body as electro-therapeutists, it is well that we should keep constantly before our minds that if we have a patient on the insulated stool, and connected by means of a conductor to one of the poles of an electric machine, and if the other pole is also connected to the patient, the stool, or platform, while we work the machine, there seems to be no effect; we cannot get the faintest spark from our patient, yet we are moving electricity in a closed circuit; a current is flowing. It is as if an India-rubber tube were attached to a pump, the free ends of the tube dipping into the same tank. Here we are dealing with the purely conducting elements; the strain phenomena are absent, therefore we can have none of the effects of static electricity, and the current which is flowing is so small that it is not appreciated by the patient. The reason we get such a small current is that, though we have got an enormous electro-motive pressure or potential (60,000 volts; say, equal to a battery of 60,000 Daniell cells), the resistance in the machine is so great (since there are so many dielectrics between the rubber and the prime conductor) that the electricity is almost all expended in overcoming this tremendous resistance, amounting to possibly millions of ohms. But if the conducting chain in connection, say, with the negative pole be allowed to fall to the earth, and the machine worked, a different state of things is seen. The patient is charged with positive electricity; at the same time the walls or floor of the room are charged with exactly the same amount of negative electricity,—that is, the positive charge on the patient has, by induction across the dielectric, produced an equal and opposite charge.

Now, if we approach the patient with an earth-connected conductor, —that is, a conductor in connection with the walls or floor of the room,— the charge of electricity is increased; "the capacity of a conductor is increased by bringing an earth-plate near it," the reason being that we are simply thinning down the dielectric. The thin-walled elastic medium takes much less force to distend it than would the thick mass of dielectric reaching from the body to the walls or floor of the room. By approaching the body with an electrode connected to the earth by means of a chain, we do this; and when the ball of the electrode has been brought near enough, the strain in the dielectric has become so great that it breaks down, a disruptive discharge ensues, accompanied by a spark.

In fact, we have converted static into kinetic or current electricity, having electrolytic heating and other effects of a true current. But it is oscillatory in character; the rapidity of this oscillation is very great, and may reach as high as a hundred million vibrations per second.

We have arrived now at a point of the greatest importance to the electro-therapeutist, and that which requires most careful consideration. We have seen that the insulated body in connection with the machine is virtually the inner coating of the Leyden jar, the outer coating being represented by the electrode in the hands of the operator; the dielectric between them—as we have had frequent occasion to mention—is in a condition of strain. The force producing the strain is a " stress," or, as it is sometimes called, the electric tension; at the point opposite the ball of the electrode there is a tendency to stretch this part of the body outward, as it were, to tear off part of the surface. When the spark occurs there is a quick forward movement of the electricity away from the body, with an equally rapid recoil. The duration of the whole spark has been estimated to be all over in the hundred-thousandth of a second. If we view the human body as a conductor, such a current would, I am afraid, penetrate to no appreciable depth. But experience tells us that a static-spark current does penetrate. To my mind, we must get rid altogether of the idea of thinking of the human body as a conductor in the same sense that we speak of metal as being a conductor. It conducts electricity, it is true; but it conducts it very badly. Nearly all bodies will conduct electricity more or less; but my contention is, that the human body is made up of conductors and insulators, or dielectrics; the skin with all the transparent tissues are dielectrics, the fluids being conductors. Now, this is just the combination that we require to transmit the spark current; and the electricity that resides upon the surface of conductors, as it were, soaks in here. If an insulated conductor be placed in a polarized dielectric between a charged conductor and the other conductor be an earth-plate facing it, and a constant difference of potential be maintained between them, the electricity in the dielectric acts inductively on the conductor, inducing a negative charge on the near side and a positive charge on the far side; the electricity has, as it were, slipped through the conductor, and the insulating medium has to bear a greater strain, though the electro-motive force is the same and the charge is increased.

If the dielectric were supposed to be stratified, each stratum of such dielectric, being strained, pushed forward like an elastic partition by the electricity trying, as it were, to get to the conductor whose potential is lower, then, if one of these strata gave way, there would be some further forward movement of the electricity, but the strain would have to be borne by fewer strata; the strain, therefore, on those remaining would be greater. By placing a conductor in a polarized dielectric we replace one or more of such strata. The human body, as I have said, is a very bad

conductor of electricity; this is common knowledge to us all in death from lightning. We know that it makes little difference what metal we use for a lightning-conductor, as the electricity slips along on the extreme outer skin, and does not penetrate sufficiently to find out whether the conductor be silver, copper, or iron. With Faraday's conducting-tube experiment before us, I think we must be compelled to view the human organism as made up of dielectrics and conductors; I do not see any reason to depart from the former statement I have made—though now dealing with organic matter—that insulators are transparent bodies, and conductors are opaque. The skin I consider a dielectric,—I do not say a perfect dielectric; there may be strata that slip more or less like the conductor in a polarized dielectric, though I should say that none of them slip so much; there is, however, a likelihood of differences in bearing strain. Static electricity having penetrated far, there may be next some fluids that allow a complete slip, electrolytic action being the means of conveying the electricity to the next dielectric (some transparent tissue,—sheaths of nerves, forms of fibrous tissue, etc.), which entangles the electricity and takes up the condition of strain, and so on. All this, let it be remembered, is due to static electricity alone, the body being charged from the prime conductor of the machine. It is hard to conceive, without such an explanation, what possible benefit is to be derived from static insulation alone (electric bath, or the souffle (electric wind); but I, for one, have not the slightest doubt of the excellent effects derived from the two latter applications of static electricity, independent of all suggestion or expectant attention. Now let us see what occurs at the moment of discharge. The electricity is straining the dielectric, both inside and outside the patient's body. Of course, the air part of this strain is the more perfect, as there are fewer slipping strata; in the dielectric within the body, however, there may be a good deal of this, causing a certain amount of leakage; so that the air strata have to bear the greater part of the strain. At the moment of discharge the elastic partitions or strata are broken down, the electricity is released—it surges forward—and as rapidly recoils backward. An obvious fact is that when the distorting force is removed the medium will spring back to its old position, overshoot it on the other side, spring back again, and thus continue oscillating till the original energy is rubbed away by viscosity or internal friction. Now released, there is no dielectric to restrain it; it is a true current, but an oscillating one.

MACHINES.

We have seen, first, that bodies may be electrified by friction; secondly, by induction or proximity to an electrified body; thirdly, that electrified bodies not only attract non-electrified bodies, but communicate electricity to them by contact; and, fourthly, that bodies similarly electrified, either by each other or from the same source, show mutual repulsion. These principles underlie the construction of all electrical

machines. The simple plate-glass machine consists of a large disc or plate of glass revolving on a horizontal axis, the axis of the plate passing through wooden supports, and the handle which turns the machine is made of glass; as the glass plate revolves it is rubbed against by two sets of rubbers, one above and the other below; at an angle of ninety degrees from each of these rubbers there is fixed a bent brass rod, surrounding but not touching the edge of the plate, and furnished on the side presented toward the plate with small, projecting spikes; these two brass rods are attached to the ends of a thick brass conductor, supported on

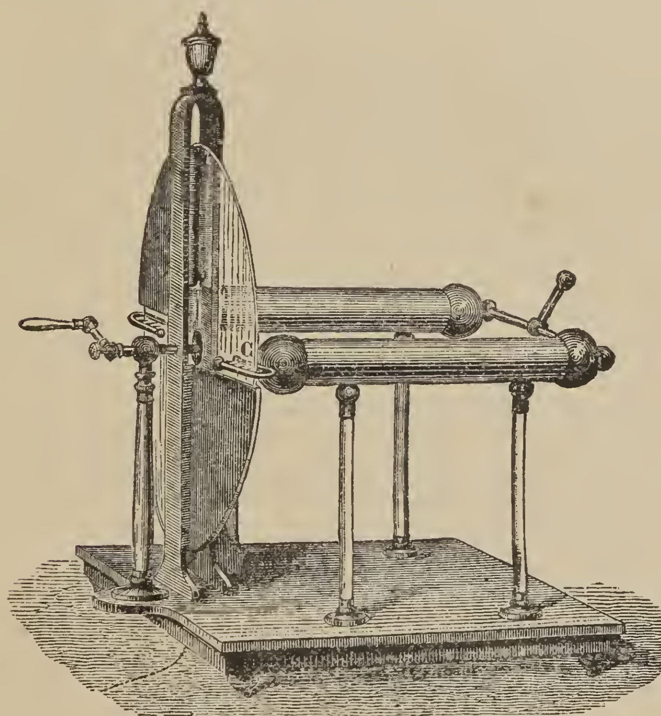


FIG. 1.—ONE FORM OF PLATE-GLASS MACHINE (THE RUMSDEN).

an insulating stand, usually made of glass. This is known as the prime conductor; it need not have any special form, except that every part of it must be rounded, with the exception of that presented toward the glass plate, as we have seen that the electricity of a conductor always distributes itself entirely on the surface of such conductor, and in such a manner that the accumulation of electricity is always greater at the most pointed parts, and least at the most rounded. As we have seen that the electricity upon any conductor tends to drive away the electricity upon another conductor in the neighborhood, so, in like manner, the electricity on a conductor behaves to the electricity on the same conductor. At

every point of a conductor there is a force acting outward from it which tends to break down the insulation of the air or other dielectric surrounding the conductor, and to cause the escape of the charge. This force is greatest where the accumulation is greatest,—at the most pointed parts, in other words. It follows, therefore, that the conductor should be round—having no points or edges—except opposite the glass disc; for here we wish to facilitate the flow of electricity between the conductor and the glass. Before using the machine a little amalgam of mercury and tin rubbed up with some tallow is smeared over the rubbers, as this is found to promote the transfer of the electricity. When the handle is turned and the glass plate revolves, it becomes electrified positively by friction against the rubbers. The rubbers at the same time become negatively electrified, which electricity flows to the earth; or, as far as our knowledge goes, we may say, with equal reason, that the rubbers lose positive electricity, and, to supply this, more positive electricity flows up from the earth to the rubbers, and the rubbers are connected to the earth. As the plate turns around, the positive electricity is brought opposite to the points. The positive electricity on the plate, as the latter passes between the points, drives the positive electricity of the prime conductor to the farther part, and therefore leaves the points and that portion of the prime conductor in their neighborhood with a deficiency of positive electricity, or, as we may say, electrifies them negatively. There will therefore be a force acting upon the electricity on the points, tending to drive the negative electricity outward from the points toward the glass, or, in other words, tending to draw positive electricity away from the glass plate on to the points of the conductor. The part of the glass plate opposite the points thus loses the greater portion of its charge. In passing through the second pair of rubbers, it again becomes charged as before; this charge is delivered up to the second set of points. This process continues until the potential of the conductor is so nearly equal to the potential of the plate that the force between them becomes too small to cause any further transfer of electricity. If, however, some outlet be provided for the electricity which accumulates upon the prime conductor, the action may be continued indefinitely. This is the simplest form of electrical machine, but is seldom used in medicine.

At the present time influence or induction machines are very generally used by electro-therapeutists. Before studying their action, it would be as well to give a short description of an "electrophorus." This simple instrument was invented by Volta, in 1775, for obtaining a series of charges of electricity from a single charge. It consists of (1) a generating plate,—a flat, round cake of resin, sealing-wax, shellac, or vulcanite contained within a metal dish or resting upon a metal plate; (2) this metallic plate or dish is called the "sole"; (3) a disc of metal of slightly smaller diameter, having attached in the centre an insulating handle, which is called the cover or collecting plate. The method of charging is

as follows: We warm the generating plate until it is quite dry, then rub it with flannel or strike it with a fox's brush; this makes negative electricity manifest on the upper surface of the cake; now, as we know, the cake is a dielectric, and the layers or strata composing it are in a state of strain, consequent on the charge it has received; it induces positive electricity on the upper part of the sole, and, as the cake is uninsulated, the negative electricity escapes to the earth, or, as we might say, a positive charge comes from the earth. So the plate has a positive charge of electricity and the cake a negative charge. Place the cover, by means of the insulating handle, on the generating plate; the two discs do not touch intimately, for there is an air-film between them; we have therefore a negatively-charged body separated from a conductor. The consequence is that induction takes place,—a positive charge attracted to the lower side of the disc, a negative charge repelled to the upper surface. If the cover is touched with the finger, the free negative electricity escapes through the body to the earth, or we may regard it as being neutralized by positive electricity flowing from the earth through the body and hand. Remove the finger, and the positive charge on the cover is, as it is said, "bound" by the negatively-charged plate. The cover is then lifted by the insulating handle, and is found to possess a charge of positive electricity sufficiently strong to yield sparks when the knuckle is presented to it. If the generating plate be perfectly dry, this may be repeated many times from the same charge given to the cake. These series of events go on rapidly and continuously in all influence or induction machines. Suppose we have an insulated, uncharged conducting vessel or shell, B, and a positively-electrified conductor, A, insulated, and we introduce A into B, not touching the side, the interior surface of B will be charged by induction with a quantity of negative electricity equal to the quantity of positive electricity on A; at the same time the exterior surface of B will be charged with an equal quantity of positive electricity. The position of A inside B will not affect the amount of these charges. It will affect the distribution on the inner surface of B, but on the exterior surface of B the distribution will be unaffected by the position of A, being determined by the form and position of the walls and floor of the room where the experiment is performed; changing the position of A inside B will not affect the potential of B. If A be allowed to touch B, the opposite charges upon their opposed surfaces cancel each other, leaving B wholly charged with a quantity of positive electricity equal to that originally on A. If A be now withdrawn, recharged with positive electricity and introduced inside B without touching, it will induce a new negative charge on the interior of B; a new positive charge will now be added to that already on the outside of B. If A now touches B, the opposed charges on the opposed surfaces will again cancel each other, leaving two positive charges on the exterior of B; this process can be repeated any number of times, so that we can give B an indefinite num-

ber of charges. When A is wholly inside B each charge added raises the potential of B, which may be raised in this way indefinitely above that to which A is charged by the source of electricity. In bringing A toward B while both bodies are charged, say, positively, we work to overcome their repulsion, and by the time A has passed inside B there has been sufficient work done to raise the potential of A above that of B; though A when it received its charge was at a much lower potential than B. We see that a charged body introduced inside a conducting shell, and then brought into contact with it, gives up its charge wholly to the shell, no matter what the relative potentials of the two conductors may have been before the one was brought inside the other.

All induction or influence machines depend, for their actions, on the foregoing principle. If we take two such insulated shells, B and C, and give a slight charge of positive electricity to B; and now take an insulated brass ball and bring it near the conducting shell, B, but not touching it, the positive charge on B induces a negative charge on the side of the ball next it; we now touch the ball with the finger, and the effect is we withdraw the repelled positive charge, leaving the ball with a negative charge. Now place the ball inside the uncharged shell, C, and allow them to touch. As we have previously seen, the negative charge is entirely given up to the shell, C. If the ball be removed from C and held near the outside of C, a positive charge is induced on the side of the ball next C and a negative on the other side. Touch the ball with the finger and the negative charge is conveyed to earth, and we have the ball with a positive charge; this charge can be given up to B by placing the ball inside it and allowing it to touch, which increases the positive charge already on B. This increased charge on B is then used, in the same manner as the original one, to electrify the ball negatively, and, the charge on B being increased, the negative charge on the ball will be greater than before. This is given up to C in the same manner as before, and the increased negative charge on C is used to develop by induction an increased positive charge on the ball, which is transferred again to B. If we continue this process, the difference of potential between C and B may be so increased that if they are brought close together a spark will pass from one to the other. An influence machine simply consists of an arrangement for carrying on such a series of operations as has just been described in rapid succession.

A revolving carrier or series of carriers is used, together with an inductor or series of inductors, between which and the carrier a certain small difference of potential must be excited in order that the machine may start. The carriers as they pass the inductors are electrified by induction, and when passing out of the influence of the inductor they are touched by a spring in connection with a collector, which in its turn acts as an inductor, and in this way a very small difference of potential can be rapidly increased to a considerable extent. With the other forms of

influence machines it was necessary to begin by electrifying one of the conductors. Influence machines, however, are now made which are able to excite themselves without external assistance, by means of a small difference of potential which invariably exists between the inductors, and which is sufficient to begin the series of operations.

The lower part of Carré's dielectric machine, as seen in the cut, is a plate of glass supported on vulcanite pillars; in fact, is an ordinary plate-glass machine with only one set of rubbers, which are uninsulated; it is turned by the ordinary handle; above this and on supports, overlapping the glass disc in its upper half, is a larger disc of ebonite, which is made to revolve at the same time as the glass disc, but necessarily at much greater speed; both plates are surmounted by a large brass

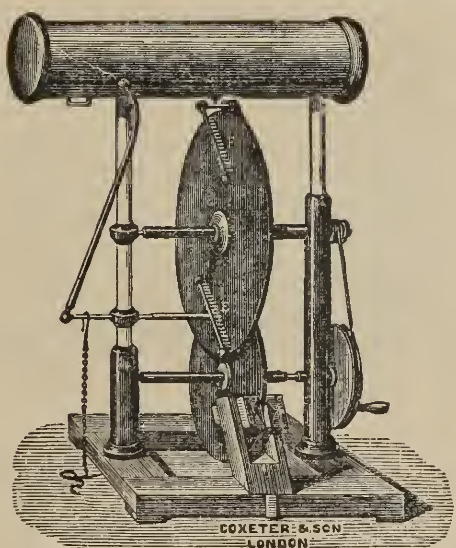


FIG. 2.—THE CARRÉ DIELECTRIC MACHINE.

cylinder,—the prime conductor,—from which projects a brass rod having a number of points for collecting the electricity from the ebonite plates. We thus see an illustration of the electrophorus, a quantity of electricity being supplied by the glass plate, but which is positive electricity of the same sign appearing on the side of the ebonite plate next the points; the upper set of points, *F*, taking up the positive electricity; the lower set, *E*, being connected to the earth by means of the chain.

This machine is made in three sizes, all of which produce a fair quantity of electricity. The second size is the one generally used by electro-therapeutists, the diameter of the ebonite plate being twenty-one inches, that of the glass fifteen inches. This machine, under favorable conditions, gives a spark of about ten inches. It is very reliable in most atmospheric conditions.

The Wimshurst influence machine consists of two circular discs of ordinary window-glass, mounted upon a fixed horizontal spindle in such a way as to be rotated in opposite directions, at a distance apart of not more than one-eighth of an inch. Each disc is attached to the end of a boss, of wood or ebonite, upon which is turned a small pulley. This is driven by a cord or belt from a large pulley, of which there are two, attached to a spindle below the machine, and which is rotated by a winch-windle, the difference in the directions of rotation being obtained by the crossing of one of the belts. Both discs are well varnished, and cemented to the outer surface of each are twelve or more radial, sector-shaped plates of thin brass, disposed around the discs at equal angular distances apart. The two sectors situated in the same diameter of each

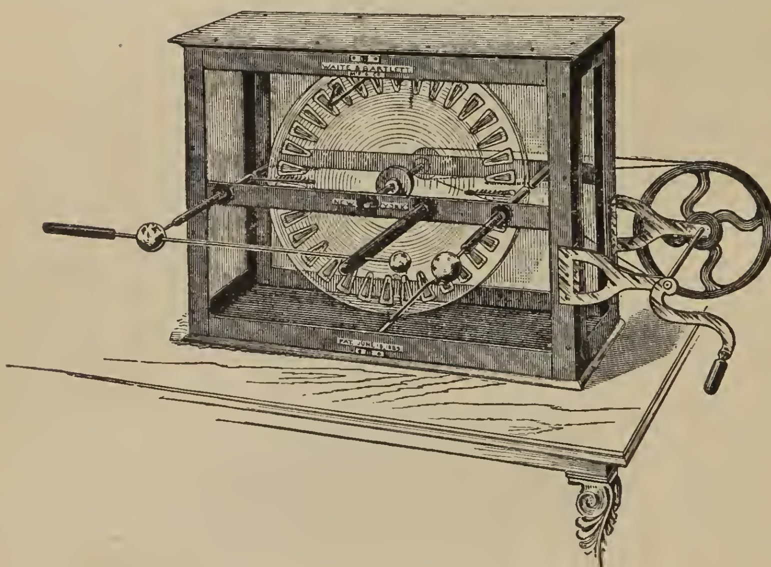


FIG. 3.—THE WIMSHURST INFLUENCE MACHINE.

disc are twice in each revolution momentarily placed in metallic connection with one another by a pair of fine-wire brushes attached to the ends of a curved rod, supported at the middle of its length by one of the projecting ends of the fixed spindle upon which the discs rotate, the brass sector-shaped plates just grazing the tips of the brushes as they pass them. The position of the two pairs of brushes with reference to the fixed collecting combs, and to one another, is variable, as each pair is capable of being rotated on the spindle through a certain angular distance; and there is, as in the case of the collecting commutator brushes of dynamo-electric machines, one position of maximum efficiency. In this machine it appears to be when the brushes touch the discs on diameters situate about forty-five degrees from the collecting combs and

ninety degrees from one another. The fixed conductors consist of two forks furnished with collecting combs directed toward one another and toward the two discs which rotate between them, the position of the two forks, which are supported on ebonite pillars, being along the horizontal diameter of the discs. To these collecting combs are attached the terminal electrodes, whose distance apart can be varied by the two projecting ebonite handles shown in the illustration. These collecting combs appear merely to convey the electric charge to what may be called the external circuit, for the induction action of the machine is as rapid and powerful if both are removed and nothing left but the discs and brushes; when in the dark, the machine being worked, the whole apparatus bristles with luminous electricity. The machine is, moreover, self-exciting, requiring neither friction nor the spark from any outside electric exciter to start it.

An extract from *Nature*, May 3, 1883, says: "It appears that in this machine the metal strips affixed to the plates act both as inductors and carriers. Suppose the front plate be rotating clockwise and the back plate counter-clockwise. If the metal strips descending from the summit on the left on the back disc are charged positively, the metal strips ascending on the front disc from the left will, as they pass under the momentary touch of the brush, acquire a negative charge. As these negatively-charged strips of the front plate advance toward the right, they will come to a point where they are opposite to the upper end of the hinder diagonal conductor, and here, whilst still acting as carriers to bring the negative charge round to the right side, they will act as inductors, and will influence the strips of the back disc, which will, as they are in turn touched by the hinder brush, acquire positive charges. The strips on the front disc will therefore constantly carry a negative charge as they move over the top from left to right, and those of the back disc will carry a positive charge from right to left. In the lower halves of their respective rotations the inverse of these actions will hold good, the front carriers conveying positive charges from right to left, the back ones conveying negative charges from left to right. The result will, of course, be that the two main conductors on the left and right will become, respectively, positively and negatively charged. If dry and free from dust the machine excites itself, and, after a couple of turns have been given to the handle, discharges sparks freely. If the two main conductors are respectively joined to the inner and outer coatings of a large Leyden jar, the discharges take place with short, loud sparks of great brilliancy. If from any cause the machine does not at once charge itself, gently rub with a silk handkerchief either of the ebonite pillars."

Professor Lewandowski claims that his machine, differing in its construction from all hitherto-known influence machines, answers the therapeutist's purpose better than any other; the merits claimed for it being that it is uninfluenced by moisture and temperature, as the generating

part of the machine is inclosed in a cylinder. The following figure represents the machine, and the principle of this contrivance consists in the employment of two hollow drums of idio-electric bodies, of which one is somewhat smaller than the other and is shut up perfectly air-tight within the others; both rotate round the same axis, though in different directions. The two vertical iron supports, $a\ a_1$ and $b\ b_1$, are screwed to the

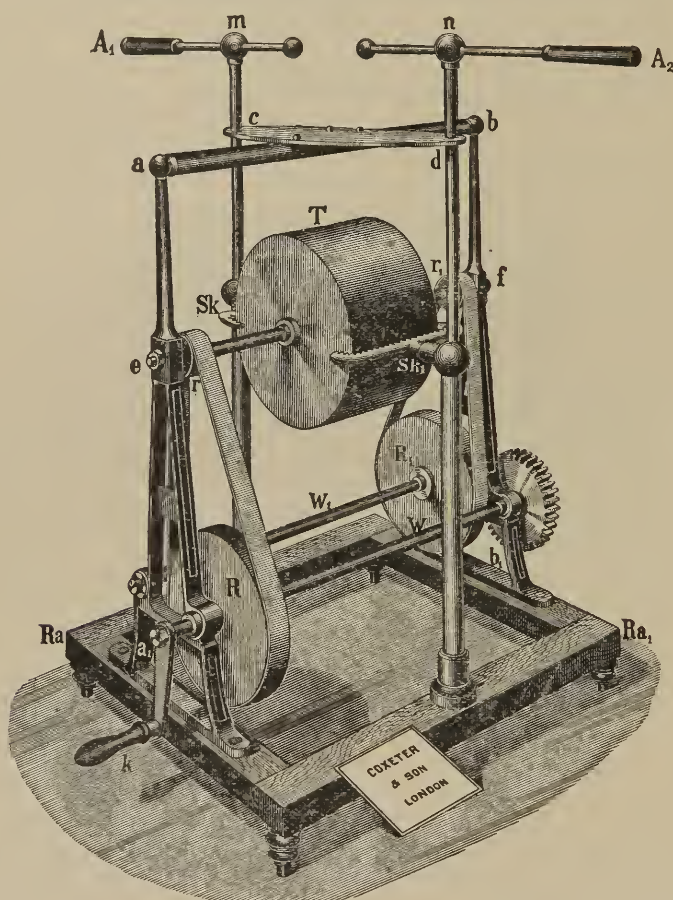


FIG. 4.—PROFESSOR LEWANDOWSKI'S MACHINE.

rectangular wooden frame *Ra* and Ra_1, seventy by fifty centimetres, their tops being joined together by the vulcanite rod, $a\ b$. These two uprights support the axles, $e\ f$, W, and W_1, which are parallel to each other. The axle, $e\ f$, is fixed and made of steel. Upon the chief axle, $e\ f$, there are two vulcanite collars, one of which is joined to the pulley, r, and the other to the pulley, r_1. In the middle of the two collars there are, on the chief axle, two hard-gum cylinders, one within the other, T, T_1 (Fig. 5).

The pulley r is connected with the internal cylinder, T_1; whereas the pulley r_1 is connected with the external cylinder, T; so that the internal cylinder and the external one can be rotated quite independently. The two lower axles, W and W_1, each carry a large pulley, R and R_1, and a toothed wheel; the large pulleys, R and R_1, are respectively united by means of straps to the superior pulleys, r and r_1. The axle, W, moreover, carries the handle, k. This whole arrangement allows the two cylinders to be turned in the reversed direction, when the handle rotates only in one direction. The wooden frame carries, besides, two uprights, the lower parts of which are made of glass and the upper of metal; they terminate in the metallic knobs, m and n. In the middle of these supports are two metallic knobs, Sk and Sk_1, each carrying a collecting comb in close proximity to the external cylinder; whilst one metal double comb, sk sk_1, inclosed in the small cylinder, is carried by the fixed axle, $e f$. In the balls m and n are the conductors, A_1 and A_2,

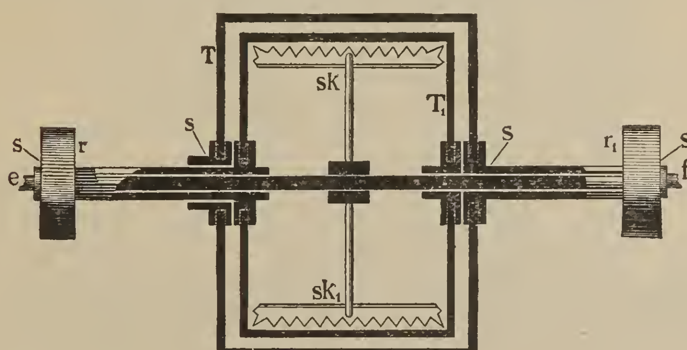


FIG. 5.

which can be moved to and fro horizontally. The turning of the handle, k, brings about the rotation of the outer cylinder, T, through the transmission of movement by means of the pulleys R and r; whilst at the same time, in consequence of the turning of the toothed wheel, the axle W_1 rotates in an opposite direction, and this motion carries the small cylinder, T_1, over by means of the pulleys R_1 and r_1. If the knobs of the conductors are brought near each other so as to come into contact, when the handle is turned in any direction it suffices to touch the surface of the external cylinder with a piece of hard caoutchouc, which has been slightly rubbed on the clothes, either above or below the middle of the drum (corresponding with the middle of the inner vertical double comb). This exciting or charging of the machine is manifested by a whizzing sound. If the motion be stopped, the electric charge of the cylinders lasts for several hours. If the handle be turned in the opposite direction, the machine does not become uncharged.

Atkinson's Toepler electric machine is an electro-static machine, of

high tension and large quantity, whose sensitiveness to atmospheric influences does not interfere with its practical working. It is made with two circular plates of glass, one stationary, the other revolving close in front of it; two sets of combs and two Leyden jars, with a switch between them. To the back of the stationary plate are attached two sets of paper and tin-foil *inductors*, connected with which are two wire brushes, and to the front of the revolving plate are attached six metal *carriers* with

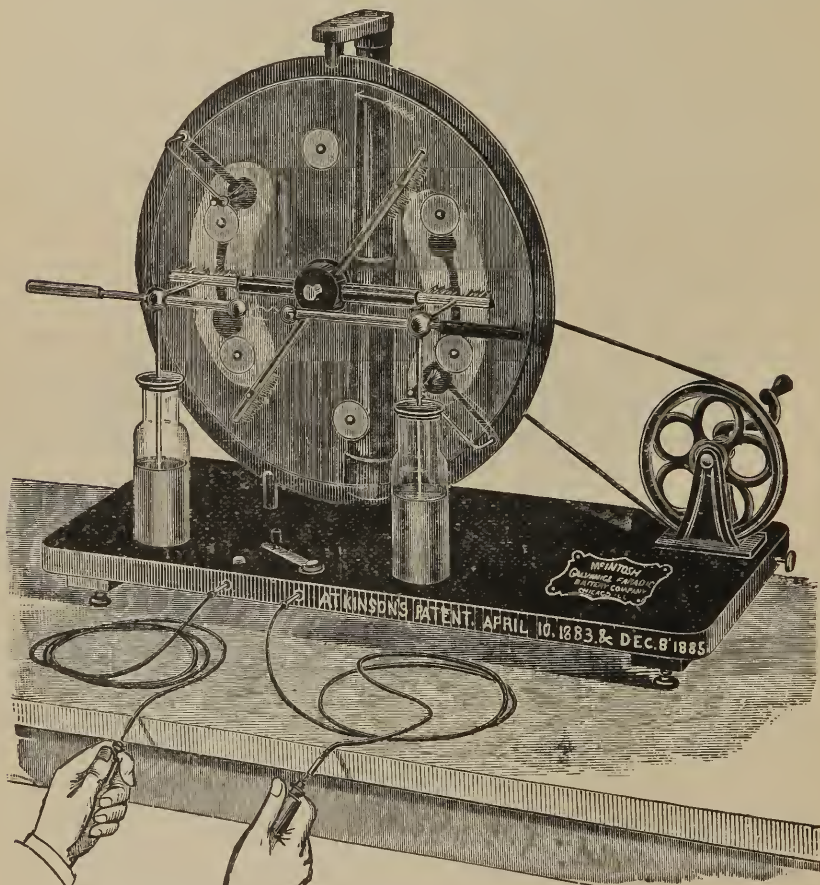


FIG. 6—ATKINSON'S TOEPLER ELECTRIC MACHINE.

raised centres, which are brought into contact with the brushes as the plate revolves, and generate the electric charge, which is rapidly increased by induction. Opposite parts of the plates and opposite inductors and carriers become oppositely electrified, condensation takes place in the jars, and sparks pass between the sliding electrodes, which may be increased to seven inches or more in length. Electricity is generated at once, and the electric charge constantly sustained by the friction of the carriers

and brushes; hence the machine remains in practical working-order under the most unfavorable atmospheric conditions.

The switch, as seen in the cut, is placed between the Leyden jars, and in connection with their outer coatings, so that the induced current between them is controlled by the operator. As this current flows at the same instant with the discharge between the sliding electrodes

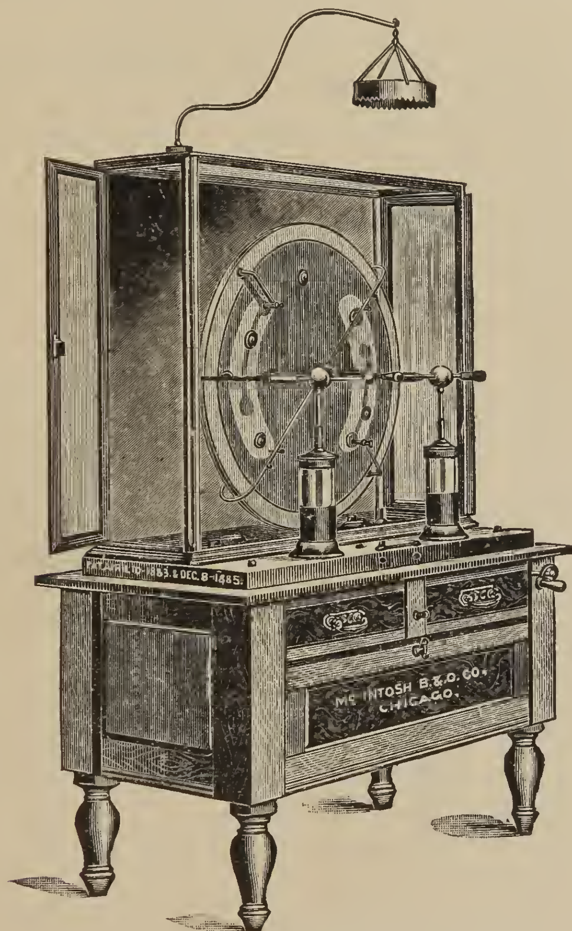


FIG. 7.—ATKINSON'S TOEPLER ELECTRIC MACHINE.

connected with the inner coatings, it is only necessary to separate them to obtain the interrupted induced current similar to the faradic. In connection with the switch are seen cable cords and electrodes, which may be held by insulating handles and applied to any part of the body. Opening the switch changes the current to the cords and electrodes, and on separating the sliding electrodes the faradic effect is at once produced, which may be varied from the slightest tremor to the most violent mus-

cular twitchings. A separation of one-sixteenth of an inch produces a mild, pleasant sensation; one-eighth to one-fourth of an inch becomes painful; while a separation of one-half to three-fourths of an inch can hardly be borne by the strongest nerves. When the switch is closed and the sliding electrodes drawn out beyond sparking distance, a person seated on an insulated platform and connected by cable-cord with the ball surmounting the Leyden jar farthest from the driving-wheel will receive a condensed charge of positive electricity, or of negative if connected with the jar nearest the driving-wheel.

In damp, warm weather, a film of moisture sometimes settles on the glass plates and temporarily suspends insulation, so that the machine ceases to generate. The effectual remedy in such a case is to dry and warm the plates, which may easily be done in a few minutes by placing one or more kerosene-lamps near them. The warming is as important as the drying, to prevent further deposition of moisture on the surface.

The Franklinic Interrupted Current and Static Induction.

A very important advance in the application of static electricity was made by Dr. Morton, of New York, in 1881. This was the introduction of what he terms the franklinic interrupted and the static induced currents. As we have seen, in drawing a spark from the patient on the insulated platform, we break down the dielectric between the metal ball and his body and, by doing so, cause a real current of electricity to pass, and close the circuit. The two coatings of the Leyden jar have been connected. The patient's body is brought in contact with the earth by means of the chain on the electrode, and, as one pole of the machine is earth connected, the circuit is thus completed. At the same time, we must remember that the current we have produced is an alternating one. In this case the patient receives the spark, the circuit being broken at the patient's body. But we could quite conceive that the circuit might be broken at any part of it,—say, a foot from the patient's body,—he himself holding a piece of brass rod or other conductor having an insulating sheath, the ends of the rod terminating in two brass balls, and one end of this rod applied directly to any part of the body to be acted on. If we now, instead of drawing a spark directly from the body, draw it from the external brass ball, the disruption takes place then between the external end of the conductor held in the patient's hand and the ball of the electrode in the operator's hand. At the moment of the occurrence of the spark the patient receives the rapidly-alternating current through the electrode held in his hand. The current might be broken at any part of the circuit, and the patient as part of the circuit feeling the effects. Dr. Morton has constructed an electrode for application of the franklinic interrupted current. It breaks the circuit at some distance from the patient's body; the end next the body may be a moist

sponge or other terminal, such as is used in applying the faradic current. There are two brass balls which constitute the circuit-breaker; these can be separated and brought together by a movement of the operator's finger. The spark passes between them and can be regulated by the distance between the balls.

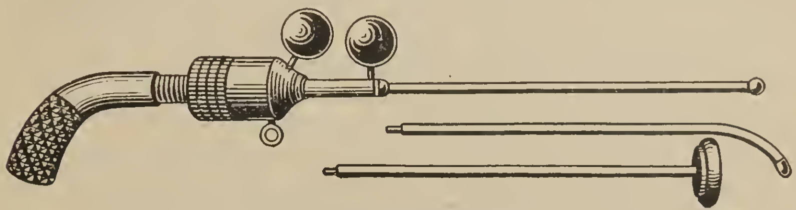


FIG. 8.—MORTON'S ELECTRODE.

STATIC INDUCED CURRENT.

Dr. Morton says: "For this current the electrodes and conducting cords must be especially constructed; the metal within the sponge of a plate should be rolled back upon itself at its edges, so as to present a rounded peripheral contour, or, better still, it should be a ball of about an inch in diameter; the handles of the electrodes should be long and made of ebonite; the conducting cord should consist of a thick strand of fine wire well insulated by gutta-percha. These precautions are necessary, owing to the great 'tension' of the current, and its consequent disposition to break down insulating barriers, which in the case of ordinary currents would suffice to confine them to their proper conductors. To use the current, bring the discharging rods of the machine into contact. If the Holtz machine, remove the connecting rods which *unite* the

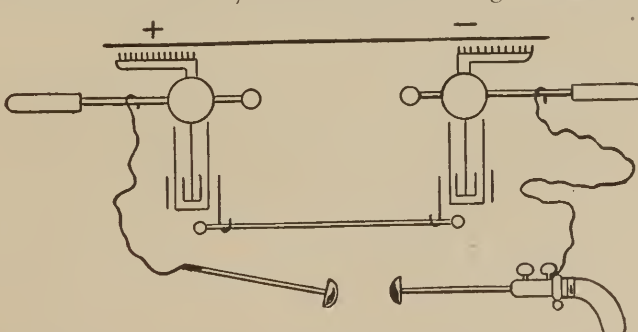


FIG. 9.—DIAGRAM ILLUSTRATING CONNECTIONS FOR INTERNAL TREATMENT BY THE STATIC UNIVERSAL ELECTRODE.

two Leyden jars and hook on the two conducting cords and electrodes. The patient need not be insulated. If now the wet electrodes be grasped, the machine set in motion, and the discharging rods separated a very small fraction of an inch, the current will be felt, and may be graduated to any strength desired or bearable, and may be localized in its applica-

tion, internally and externally. In the machine of Carré jars of about eight ounces in capacity are used, and are simply suspended from each conductor by means of a hook; to the outer coating of the jars are attached the conducting cords with the moist electrodes; the poles in this machine may be separated for about an inch. The strength of the current is determined by the size of the jars and amount of separation of the poles. Nerve and muscle may be acted on in exactly the same way as in the application of faradism, but, to my mind, in a much more effectual and less painful manner. I have seen muscles react to this current when not the slightest reaction could be obtained from the strongest bearable application of faradism, using both coarse and fine coil. This form of electricity, by means of special electrodes, can be used for the vagina, uterus, or other internal canal or cavity (as shown in diagram)."

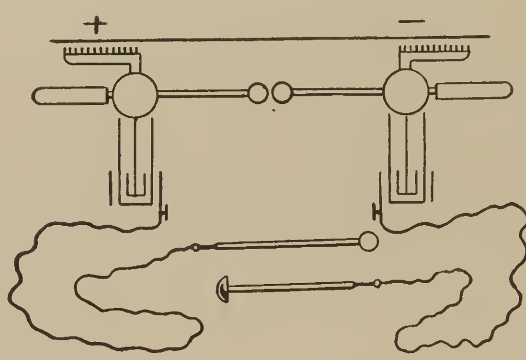


FIG. 10.—DIAGRAM ILLUSTRATING STATIC INDUCED CURRENT, WITH ELECTRODES FOR INTERNAL TREATMENT.

CHOICE OF MACHINE AND METHODS OF APPLICATION.

In the application of static electricity in electro-therapeutics the first consideration presenting itself is the choice of a machine. Almost all the types in use at the present time are good. De Vigourout, of Paris, whose experience of static electricity has been very great, speaks most highly of the Wimshurst machine and that of Carré. The Holtz machine appeared to him to give too much electricity and to have too exciting an effect upon certain patients. He says, "We must not attach too much importance to these questions of apparatus, but I will say there is an advantage in using large machines. The discs of the Wimshurst at the Salpêtrière are seventy centimetres, and I have actually tried one of one metre. It seems impossible to obtain good effects from small machines, which cannot be used without a condenser, and which patients are ordered to buy, with the injunction (too common an error) to treat themselves." My own experience would correspond closely to this. The main object is to get a machine that you can rely on in all atmospheric

conditions, giving a fair quantity of electricity at a sufficiently high pressure or potential.

METHODS OF APPLICATION.

1. *The Electric Bath, or Static Insulation.*—The patient is placed on the insulated platform, in communication with one of the poles of the machine,—say, the positive. After some turns of the handle he is found to be charged with positive electricity of a high potentiality, at the same time offering means of a constant waste of electricity from all parts of his body and clothes,—waste which is continually repaired by the electricity flowing from the conductor of the machine. The physiological and therapeutical effects of the electric bath cannot be doubted. This is the base of all treatment by static electricity, and might even constitute it entirely; after at least a few sittings its action is purely sedative.

2. *The Electric Souffle, or Wind.*—This is obtained by directing the point of a metallic, uninsulated rod toward the patient, at a distance of about a foot, by induction; the point is electrified negatively (that is, if we are using positive electricity); it communicates its electricity to the adjacent air-molecules or dust-particles; they are thus attracted to the nearest part of the patient's body, and we have a discharge by convection, by a stream of particles producing an actual current in the air. The action of the souffle as a sedative is most remarkable, and may be compared with the galvanic anode, but it is found to be more energetic.

3. *Sparks.*—These are obtained by bringing a metal-ball electrode sufficiently near the patient that the dielectric between the ball and the body is broken down; they are used to excite muscular contraction by acting on the muscle direct, or on the nerves supplying the muscles, and to excite cutaneous sensibility.

4. *Aigrette.*—This is produced by bringing a rather blunt metal point or a piece of wood near the patient's body. We have no electric wind or spark, but an intermediate form of discharge. When the point is positive it is a luminous brush of a bluish or violet color. This form of application is especially useful in the treatment of nervous patients, where we wish to lead up to stronger applications, or where we want to act upon a sensitive surface, as the face.

5. *Electric Current.*—This is effected by passing a metallic, uninsulated ball more or less rapidly over the patient's clothing. It thus produces a multitude of little sparks, whose length is measured by the thickness of the interposed fabrics. The friction brings about a disagreeable or even a painful sensation,—smarting and burning. The skin is reddened as by stinging. Some patients whose cutaneous sensibility is dull or perverted find the friction agreeable. The reason why the friction can only be made over clothing is evident; if the ball were applied to the skin there would be no insulation, as it simply conveys the electricity to the earth; the friction, like the sparks, exercises a stimulating local action and a distant and reflex action, whose effect, on the whole, is sedative; practiced over a large surface of the body, it is distinctly stimulating. Friction made on the lower half of the body diminishes spinal congestion, such as a spasmodic state of the lower limbs, exaggerated reflexes, seminal emissions, etc. During the action of an electrical machine ozone, or distinctly odorous gas, is developed in considerable quantities. The peculiar smell which accompanies a flash of lightning is due to the transformation of atmospheric oxygen into this gas. According to Dr. Lauder Brunton the passage of an electric spark causes the molecule of oxygen to split up into single atoms, which do not, however, remain apart, but immediately coalesce either with other single atoms to re-form molecules of oxygen or with other molecules of oxygen containing two atoms to form a molecule of ozone, which thus contains three atoms. To show the presence of ozone a piece of paper impregnated with a solution of iodide of potassium is used; if the gas is present the paper will assume a deep-blue color. This gas can be administered in an effectual manner to the patient by means of an insulated electrode consisting of a small disc carrying half a dozen points. The electrode is held near the patient's open mouth (not within sparking distance), and he is required to breathe deeply, thus inhaling the ozone. This is of great service in asthma and anæmia.

COMPARISON BETWEEN GALVANIC AND STATIC ELECTRICITY.

If we take an ordinary galvanic battery—say, of 20 cells—and complete the circuit by means of a piece of fine platinum wire a few inches in length, it is raised to a white heat. If we complete the circuit in an induction machine by joining the poles by means of the same wire, no effect whatever will be observed. In the latter case the quantity of electricity is too small to sensibly heat the wire. If the terminals of a galvanic battery be two copper wires and the circuit completed by bringing them together, a small spark will be seen when they touch, but the spark is so short that it would be impossible to measure it, while with an electric machine of moderate size we would get a spark of several inches in length. If we connect a Leyden jar by its two coatings to the poles of an electrical machine and the handle is turned for some time, the jar will either burst or overflow, if the machine is powerful enough: if not, a strong spark will be obtained by connecting its inner and outer coatings. If the ends of the wires from the battery be now connected to the coatings of the jar, it will be found that, however long the battery may be left on, neither overflow nor spark will be produced. To charge a Leyden jar we require not a large quantity of electricity, but a high potential difference. The electrical machine gives a high potential difference, but a very small current; at the same time be it remembered that static electricity can do all that can be done by galvanic or dynamic electricity; it has physiological as well as luminous and heating effects; it can magnetize iron or steel and produce chemical changes. It is not improbable that before long a static machine may be invented not only giving a high voltage, but a large quantity of electricity; the problem to be solved is the lessening of resistance between the different parts of the machine.

MAGNETISM.

An ordinary bar magnet exhibits certain familiar phenomena when suspended by its centre of gravity; though free to turn in any direction, it will invariably come to rest in one position,—that is, with its poles or ends pointing north and south. The forces which turn the magnet into this position, or maintain it there, are due to the action of some other body, which may be a magnet. The space where a magnet experiences this action is called a *magnetic field*. The earth produces a magnetic field. The forces experienced by a magnet and due to the earth's magnetic field are sensibly the same at all parts of any space of moderate dimensions, as a room. Within such a space the field is said to be *uniform*, and the direction of the magnetic force is the direction which the axis of a freely-suspended magnet would assume. When the axis of the magnet does not coincide with that direction, two equal and opposite parallel forces act on the magnet; these forces tend to turn the

magnet so as to bring the axis into the direction of the magnetic force. The body producing the magnetic field experiences equal and opposite forces, tending to turn it in the opposite direction. A magnet produces a magnetic field in its neighborhood and modifies any magnetic field previously existing there. The field due to a magnet is not uniform; the forces may be much greater than those due to the earth. Magnetic fields are also produced by electricity in motion. Under the undisturbed action of the earth's magnetic field the end of the axis of any magnet points in a direction which differs at different parts of the earth's surface, but which is always northerly. If a magnet be broken into the smallest particles possible, it will be found that each particle is a magnet having two opposite poles, so that each particle possesses properties exactly similar to a bar magnet. We may imagine a magnet to be composed of molecules which cannot be further divided by physical means. This include's Webber's theory. Ampère's theory, which is now generally accepted, supposes that each molecule of the magnet has a current of electricity circulating round it. These currents are assumed to exist in all magnetic substances; before magnetization they move irregularly; after magnetization they circulate in parallel directions. If the observer face the north pole of the magnet, the currents move in an opposite direction to the hands of a watch, and, of course, looked at from the south pole, they move in the same direction as the hands of a watch. So we see that magnetism can be defined as electricity in rotatory or whirling motion.

An electro-magnet is simply a bar of soft iron, generally in the shape of a horseshoe, round which a coil of insulated wire is wound, through which a current of electricity can be passed. Electro-magnets are often used to magnetize bars of steel, as they are much more powerful than ordinary permanent magnets. We can magnetize by an electric current in the following manner: By winding silk-covered copper wire in a coil, attaching the ends to the terminals of a fairly strong Voltaic battery; move the coil from one end to the other of a bar (or a horseshoe-shaped piece) of steel, taking care to move it always in one direction. We can also magnetize by the earth's induction. If we take a poker and hold it parallel to the direction of a freely-suspended magnetic needle, we should expect that, if the poker were built up of magnetic molecules, each molecule would try to set itself in a direction parallel to the suspended needle; for we should suppose that the earth would act on the molecules of the poker as it does on the needle. The direction or dip of a suspended magnet at this part of the world is almost vertical. So we should hold the poker vertically. If we hold it thus for a few minutes and then test it for magnetism by trying whether either end of it has the power of repelling either end of a suspended magnet, it will be found that it has not acquired any sensible magnetic properties. Steel railings, however, which have remained in a vertical position for many years, have frequently been observed to have acquired magnetic properties, the lower

end having become a north pole, as we should expect, if Webber's theory be true. Now, as we know, all the molecules of the poker are closely packed together, and it is therefore quite possible that the earth may exert a force tending to set them in a definite direction, bnt that this may not be strong enough to overcome the cohesion of the molecules. If we could by some means diminish this cohesion, we might have better results; this can be done by simply striking the poker with a hammer when held in a vertical position, and it thus becomes a magnet, the lower extremity becoming a north pole; but if the poker be reversed and again struck its magnetism will be immediately reversed also. The cohesion of the molecules can also be diminished by heating the poker; when thus treated and left to cool in the vertical position, it becomes a magnet.

A slight sound is heard when a body is magnetized or diamagnetized by an electric current, and is due, according to this theory, to the sudden turning of the molecules. This production of sound during magnetization was utilized in one of the earlier forms of telephone receivers. Heat is also produced when a magnet is rapidly magnetized or diamagnetized.

We have seen that the space through which the influence of the magnet extends is the *magnetic field* of such a magnet. This force increases as we approach the poles and diminishes as we recede from them. At every point it has a definite intensity depending upon the distance from the poles; and it has a well-defined direction at every point, as indicated by the *line of force* passing through the point. We can see the general distribution of these lines of force by placing a sheet of cardboard above a magnet resting upon a table; if we sprinkle iron filings over the cardboard, and as the filings fall gently tap the cardboard, we can see that they arrange themselves along certain curves; these curves represent the lines of force.

Magnetic Induction.—A piece of iron, not of itself a magnet, will, when placed in a magnetic field, become magnetized in the lines of the magnetic force in the field. Thus a bar of iron, placed with its longest axis in the direction of the lines of magnetic force, will become a bar magnet, having its north pole at that end of the axis toward which a north pole would, under the influence of the field, tend to move.

The action by which iron becomes magnetic in a magnetic field is called *magnetic induction.* The molecnles of iron in a magnetic body before magnetization are, by Webber's theory, assumed to have their axes turned in every possible direction, the magnetic actions of the molecules thus neutralizing each other so that the body will not act as a magnet. If the north pole of a bar magnet be brought near such a body it will attract the unlike poles of the molecules and will repel the like poles; so that the molecules will tend to arrange themselves with their north poles pointing one way and their south poles another way. The molecules will thus act together, forming a magnet whose south pole will be the pole next the north pole of the inducing magnet.

In a uniform magnetic field, iron magnetized by induction is not impelled in any direction by the magnetic force, which acts with equal and opposite force on the two induced poles. When the field is not uniform, the induced poles, which are themselves equal, are unequally acted upon, and motion tends to take place in the direction in which that pole would be urged which lies in the stronger part of the field. Thus iron, in virtue of the magnetism induced in it, is attracted by either pole of the bar magnet; for the end of a piece of iron, say, near a north pole will become a south pole and will be more attracted than the distant north pole of the iron is repelled. A magnet shaped like a horseshoe having poles near the ends will attract a piece of soft iron placed opposite and across the ends to the best advantage, for each induced pole will be in the most intense part of the magnetic field which the magnet can produce.

We see here, as in static electricity, that induction precedes attraction. Iron in which magnetism has been induced can, in its turn, induce magnetism in another piece of iron.

Paramagnetism and Diamagnetism.—Other substances besides iron and steel can be magnetized by induction, acquiring properties similar to iron, but in a much feebler degree; these substances are called magnetic or paramagnetic to distinguish them from other substances, such as bismuth, which also acquire polarity under the influence of a magnetic field, but in which the direction of the induced magnetism is *opposite* to that of the magnetic force. The latter substances are called diamagnetic.

One result of these two opposite arrangements of induced poles is that all paramagnetic matter in a magnetic field tends to move from the place of smaller to the place of greater intensity of force, and that all diagnostic matter tends to move from the place of the stronger to the place of the weaker intensity of magnetic force. Diamagnetic matter is repelled, paramagnetic matter is attracted by the pole of a magnet; consequently, while a bar of iron, if free to turn, tends under the action of induction to place itself *along* the lines of magnetic force, a bar of diamagnetic matter, such as bismuth, tends to place itself across these lines. All bodies are either paramagnetic or diamagnetic, but the magnetic effects are much feebler with all known forms of matter than with iron or steel.

The Earth's Magnetism.—The earth's magnetic field is not one which could be produced by a simple bar magnet or any simple system of bar magnets. The earth has not got a magnetic pole in the sense given to the pole of the magnet. It is usual, however, to call these points on the earth's surface where the direction of the lines of magnetic force is vertical the magnetic poles. The magnetic pole situated near the northern end of the earth's axis resembles what we have called the south pole of a bar magnet; the earth's pole in the south resembles the north pole of a bar magnet.

Therapeutic Application of Magnets.—At the present time there is no evidence of a reliable nature that a magnetic field, no matter how powerful it may be, exerts any sensible influence on the healthy human organism. In certain abnormal states of the nervous system, notably in hysteria, effects of a remarkable character are produced; muscular contractions are relieved and anæsthesia temporarily cured when a large compound magnet is brought near the patient. This I have seen done at Charcot's clinic at the Salpêtrière, under the personal direction of Charcot himself. And there is no doubt that in other hands, as well as in his, they have been the means of even curing some neuroses.

At the Salpêtrière at the present time, however, magnets in the treatment of disease are little used, static electricity having almost entirely superseded them. In the use of magnets as therapeutic agents the phenomena are necessarily entirely of a subjective character, and are therefore open to many objections, amongst them being the possibility of such applications degenerating into charlatanry. Magnets are often of service in diagnosis, indicating the presence and position of needles or small pieces of steel or iron in the tissues, and are frequently a great aid in the removal of such foreign bodies. The electro-magnet is the form now generally used for such purposes.

THE FARADIC OR INDUCED CURRENT; ELECTRO-MAGNETISM; ELECTRO-MASSAGE, AND INSTRUMENTS.

By GEO. J. ENGELMANN, M.D.,
ST. LOUIS.

I. HISTORY.

The induced or interrupted current is generally termed the faradaic, or faradic, in commemoration of Faraday, to whom we owe the discovery of this form of electricity, and also the induction coil of Ruhmkorff, as a direct result of this discovery that an induced current of electricity is generated in a conducting, or closed, wire circuit placed *near to*, but *not in contact* with, another circuit through which a current is passing.

The history of faradic electricity, in its relation to medical science, is a curious and unusual one; hardly had it been discovered, three-score years ago, but its physiological and therapeutic properties were clearly defined; and it was not only at once accorded a place in medicine, but it attained a preponderance and popularity now unknown. Much has since been forgotten, and little has been added to our knowledge of this form of electricity, notwithstanding the wonderful progress in other branches of electrical and medical science.

In the early part of this century magneto-induction instruments of crude form were used here and there, but they proved unsatisfactory: the method of application was vague and general.

The first attempt at localized application, with a distinct object in view, was made by Sarlandière, in 1825, who sought to limit the effect of electricity to certain muscles and nerves by guiding the current directly to the part to be reached by means of needles, one connected with either pole, and plunged into the tissue so as to concentrate the current upon that part of the muscle or nerve between them. It is needless to say that the pain caused so far surpassed any possible benefit that this method found little favor.

Oerstedt, of Copenhagen; Ampère, Schweigger, and others led the way by their investigations to the development of this form of electricity, produced by the induction coil as invented by Faraday, who, moreover, in 1831 gave us the laws governing electro-motor induction, the induction of magnets on currents and of currents on currents, and showed that we can increase the electro motor force by increasing the number of windings of the conducting wire, as each winding or turn of wire cuts across the lines of force independently. His electro-magnetic induction experiments, during the early thirties, led to the Ruhmkorff coil, which

has ever since served for the production of the faradic, induced, or interrupted current in the laboratory, and, without the condenser, as the type for all instruments employed in medicine.

Not one of the earlier instruments has survived, but we must record, as among the first, the apparatus for the therapeutic use of voltaic induction currents constructed in 1831 by Masson, and another invented about the same time by Pixon, for the application of magneto-electric currents.

It was not until the forties, after the investigations of Faraday and the invention of Ruhmkorff, that more serviceable magneto- and volta-electric instruments came into the hands of the practitioner so that this form of electricity could be practically utilized. At first the rotary or magneto-electric apparatus prevailed, but soon yielded to the more convenient volta- or galvano- electric instrument,—gradually disappearing more and more, until at the present day it is known by name only, notwithstanding some good points which should at least preserve it from total oblivion.

The new instrument soon became popular, as it was small, easily manipulated, and gave currents of great physiological energy; powerful effects upon the nerve were felt, and upon the muscle seen as well as felt, yet little was really accomplished; the current was vaguely and indiscriminately applied until Duchenne showed that it should be localized to attain satisfactory curative results. Others as well seized upon the new therapeutic agent,—men such as Marshall Hall and Golding Bird in England, Froriep in Germany, and others; but it was Duchenne, known by the city in which he labored as Duchenne of Boulogne, an accurate observer and careful experimenter, who, by his thorough electro-physiological and neuro-pathological researches, at once firmly established the induced current on a scientific basis; and we may well speak of this great apostle of faradism as the founder of modern electro-therapeutics. Enthusiast as he was, he practically excluded galvanism from the field by confining his work to this one form of electricity; and he not alone discovered its physiological and therapeutic properties, but developed and perfected them so that but little has been added since his day. As an able contemporary truly says, he placed faradism almost where it now stands,—far ahead of the present general knowledge. If we follow the course of his investigations, from his first publication in 1847 to the final results as they appeared in his classic work, "l'Electrisation Localisée," in 1855, we shall review the more important physical, physiological, and pathological features of faradic electricity.

Duchenne, guided by the idea suggested in the impracticable experiments of Sarlandière, sought to localize the current to certain parts or organs, to confine and concentrate its effects upon nerve and muscle without influencing the skin in its passage, or to concentrate its powers upon this superficial structure without affecting the underlying tissues.

He applied the dry metallic electrode to the dry skin, and, although sparks and crackling gave evidence to eye and ear of the passage of the current, as did the superficial sensory nerves, no physiological phenomena were produced, proving that it did not penetrate; the same current, applied to the same points by means of sponge-electrodes, well moistened in warm salt water, produced neither sparks nor crackling, but nerve-pain or muscle-contraction, as it traversed sensory or motor nerves or muscles. He also found that the muscle was contracted, not only by the current directly traversing its fibre, but also, and even more effectively, by a current penetrating at certain well-defined points, not necessarily near to or directly upon the muscle. These points—which he called "*points d'election*," points of choice—were proven, by Remak and von Ziemssen, to be the points at which the motor nerve is nearest the surface and most easily reached by the current, generally near where it enters the muscle. This discovery led him to make the distinction, still upheld, between *direct* muscular contraction, produced by placing an electrode upon the muscle itself, and *indirect* contraction, produced by irritation of the nerve controlling the muscle.

His thorough studies of the muscular system in health and disease were followed by physiological and pathological experiments upon other parts, and taught him, even then, the impotence, if not danger, of the faradic current in disease of the central nervous system.

Furthermore, it may surprise some of the prolific writers of the present day to know that Duchenne, as far back as the forties, recognized the difference between coils of heavy and of fine wire,—one of the most important features in faradic electricity,—which I have endeavored to elaborate, and which has called forth the attack, the sarcasm, and condemnation of certain of the authors of modern works on electro-therapeutics. Though Duchenne made the distinction between *primary* and *secondary* coils, finding that at times the current from the one, at times that from the other, appeared the stronger, he did not clearly understand that their individuality was due not to the difference in direction or induction in primary and secondary coils, but to their quality, the length and thickness of the wire forming the coil. He found that the action of the secondary coil was more intense upon the skin, and of the primary upon deep-lying organs, especially muscles, and speaks of an "electric" action of the coils, yet recognizes that the difference depends upon physical laws; although he himself could give no possible explanation of this clearly-established fact, he denies that given by the physicist Becquerel, who claimed that the varying tension of the coils must account for this difference in the effect of the current.

The discovery of the difference in the action of primary and secondary—in other words, of heavy and fine—coils was made by Duchenne in the faradization of the bladder with one electrode in the rectum and one in the bladder: finding some irritation of the sacral plexus in the use

of the secondary, or fine-wire, coil he desired to weaken the current, and inserted the primary, or heavy-wire, coil, which, contrary to his expectation, proved still stronger and caused intense suffering. Although unable to give an explanation, he clearly established the difference in the character of the current from primary and secondary coils, making five main points, to which I shall refer in the proper place.

Barring trifling errors, and the illusions of the enthusiast, as the man must be who would succeed in any one sphere, the work of Duchenne still stands, at the present day, as the foundation upon which every method of localized electrization is based, and, I can but repeat, strange as it may seem, far in advance of the present *general* knowledge.

The faradic current was received with general favor and overshadowed all other forms of electricity as a therapeutic agent; its preponderance being due to the thoroughness and the wide-spreading of Duchenne's work, whilst novelty, cheapness, and simplicity at once made it popular: it was more readily kept in order; there were fewer elements, fewer connections; it was seen, heard, and felt; doctor and patient knew, by sparks and buzzing, by nerve-shocks and muscle-jerkings, when the apparatus was at work, whilst the cumbersome and expensive galvanic current, especially if properly used, gave no appreciable effect; the patient was not satisfied; a slight burning, perhaps, but no shocks; nothing so startling or effective, as it would seem; and the doctor, before the days of the galvanometer, often in doubt whether his battery "was working" or not.

Faradism was the one form of electricity used in medicine; the scientific researches of du Bois-Reymond and Pflüger, in 1850, upon the electrical phenomena in living animal-tissue, were the first evidences of recurring interest in galvanism. In their studies of the effect of the anodal and cathodal opening and closing currents upon nerve and muscle, which proved of such diagnostic import, the induced current played but a secondary part; and when, in 1855, Robert Remak, of Berlin, disclosed the merits of the constant current, which he looked upon as the only practically-useful form of electricity, galvanism assumed a supremacy which it has ever since retained,—in the main, I believe, because it appeared of greater import and excited a more general interest as being the form of electricity which first served industrial purposes.

Amid the triumph of galvanism the excellent work of Tripier, who, in 1860, presented to the French Academy a sledge instrument constructed by Gaiffe, with a series of coils, both primary and secondary, of varying length and thickness of wire, made no impression whatsoever, receiving but passing notice even in his own home. His name to-day is almost unknown, though the results of his labors are now appearing; he demonstrated the varying therapeutic effects of currents from differently-constructed secondary coils, and devised the first instruments for bipolar faradization of uterus, vagina, and bladder, which have recently been

elaborated and have guided Apostoli to his valuable methods of bipolar faradization.

The enthusiastic teachings of Remak excited renewed interest in electricity; "as with each important discovery men's minds turned anew to this strange agent extravagant hopes were again aroused, only again to be followed by failures;" so that, when the recoil came, and a calm survey of results actually accomplished followed the first enthusiastic laudations, the current almost fell into disrepute, as practically useless and but the agent of quackery. During my student days, in the very home of Remak, I was taught that it was without effect for therapeutic purposes, though of diagnostic value in some obscure nervous diseases. Yet from time to time a fresh impetus was given by some new theory, experiment, or discovery, and popular favor was ever readily extended to this mystic and wonderful agent from which so much was expected.

During all these therapeutic fluctuations scientific investigation continued, and wonderful progress was made in the practical application of electricity; medical thought and experiment naturally turned in the same direction, and profited by the results evolved.

A more thorough knowledge of the properties of electricity, the introduction of the polar method,—above all, of measurement and dosage, as first applied by Apostoli in 1884,—made the constant current more tractable and serviceable, and again a great wave of electro-therapeutics swept over the profession, all to the credit of galvanism, crowding out faradic electricity more and more. The persistent efforts of Rockwell have given general faradization a place, as the American method, in therapeutics; Apostoli has perfected and practically applied the methods of bipolar faradization, first indicated by Tripier; whilst my own efforts toward increasing range and efficiency of the current, by variation and increase of interruption and by gradation of coils, however successful, have altered the general situation but little as yet.

Valuable additions have been made to our knowledge of faradic electricity in recent years by scientific investigators, prominent among whom are de Watteville, with his investigations on electrical tension, in 1877; Gaertner, who studied the electrical resistance of the human body, in 1887; and Kraïewitsch, who taught the application of Ohm's law to induction currents, in 1889; Stauffer, on the quantity of induced currents, in 1890; then Weil, on fine- and heavy- wire spools, in 1891; and, lastly, d'Arsonval, the brilliant Frenchman, who has probably done more than any investigator now living to further our knowledge of the physiological effects of the faradic current.

A bar to the progress of faradism is the impossibility of satisfactory therapeutic measurement; although the physical quantity of induced currents can be determined with precision, the measurements so far achieved are no gauge of physiological effect, and even the fundamental laws of electricity fail in certain phases of this current. It can be meas-

ured in micro-coulombs and volts, and milliampères can be determined; yet this in no way indicates physiological efficiency, as character and frequency of interruption and resistance and character of coil may alter these without varying the physical qualities indicated by the measuring instrument. The quantity of electricity remains the same, however much the curve—which is indicative of physiological effect—may vary. Nevertheless, some attempts have been made at direct measurement: a faradimeter was recently promised by an able and enthusiastic American author, whose efforts have so far, it would seem, not been successful. The only instrument which has appeared is the faradimeter of Edelmann, which indicates, by a scale on the slide, the strength of the current from that one coil in volts on short circuit, and for a motive power of 300 milliampères; yet it is no more indicative of physiological effect than a scale marked at pleasure in inches or centimetres. It is a beginning, though incomplete and, I must even add, misleading as a physiological or therapeutic measure.

It may be interesting to sketch, in a few words, the development and present status of the apparatus which furnishes the induction current for medical purposes, and I am sorry to say that it well demonstrates that no progress has been made for decades since the completion of the galvano-faradic instrument, when it displaced the earliest forms of the magneto-induction apparatus.

Any instrument of the present day, of whatever make, on either side of the Atlantic, is perfect in one way; "it works well," is well made, extremely satisfactory for the price, and can be had in suitable shape for any purpose the practitioner may desire, as pocket, box, or stationary battery. But whilst all instruments now made function well and "buzz" smoothly, the great majority furnish but *one form of current*, thus greatly impairing their utility, and to this fact mainly is due the secondary position occupied by the faradic current, as well as its limited therapeutic use. The average instrument of the day is not equal to that of Duchenne, with its efficient primary, or coarse-coil, current, and is inferior to the one constructed by Tripier, in 1860, with its series of coils and variability of interruption. Some few makers, appreciative of the wants of the profession, are now furnishing superior instruments, which admit of the application of the widely-different forms of the faradic current, so essential to its efficient therapeutic application; greater range is being given to the coil and to the rate of interruption; in fact, greatly improved instruments have quite recently appeared.

Present Status of Faradic Electricity.

The preponderance given to galvanism by the labors of Remak still prevails, and has of late been strengthened by the striking effects of electrolysis, by the perfection of the polar method, and the possibility of measurement and dosage; the efforts of individual workers in the

field of faradic electricity availing but little to improve its status. Galvanism is in fashion, and fashion is a power in medicine. The faradic box is stowed away, its use is to a great extent confined to those who still deem one form of electricity as good as another, or choose their instrument for its cheapness,—a curious state of affairs in this progressive age, due to lack of interest on the part of manufacturer and electrician, scientist and practitioner, to the inferior character of the average instrument, and to ignorance of the physical and physiological properties of the induced current, which is a *terra incognita* to the majority of those who use electricity in medicine, and even but little explored by the more advanced; yet light is dawning, more perfect instruments are being furnished, and scientific investigation is perfecting our limited knowledge of this neglected form of electricity.

A brief review of assertions made in even the most recent text-books and publications by prominent writers will at once reveal the vagueness and uncertainty of present knowledge in this sphere, and may serve to explain the distrust and disregard of the practitioner for this form of electricity:—

In the International Electrical Congress, held in Frankfurt in 1891, one of the questions under consideration was "whether therapeutic results *can* be achieved by the current which can *not* be achieved by *suggestion*," and much stress was laid on suggestion as a main factor in electrical treatment, prominent in the effects claimed for static electricity, though less so in faradic and galvanic applications. Another speaker expressed the opinion that, in the use of the faradic current, the irritating action (reizende Wirkung) alone is directly or indirectly serviceable in treatment; the sedative, nerve-quieting, effect he did not mention. The Edelmann faradimeter, which is not by any means, as was intended, a therapeutic meter or measure of faradic electricity, he recommended for the laboratory or for the specialist, though too complicated and expensive for the practitioner, and, in citing the instruments necessary for therapeutic purposes, "der kleine Spanner," one of the small-sized faradic boxes, without variation of coils or interruptions, is recommended as answering all demands; and for purposes of measure, dosage, and comparison the number of interruptions and size of electrode are named; yet no means of determining or of varying the number of interruptions is given, and the main features, character, and position of coils and resistance of body are ignored.

The Edelmann faradimeter, here quietly accepted as a measure of faradism, is another evidence of the darkness still enshrouding this current; it has been accepted because it emanates from one of the most competent and scientific of electricians, with the assistance of a prominent electro-therapeutist, and is presented by them to the profession as the first instrument for the measurement of the induction current, which is to remove that stumbling-block to the progress of faradism,—the absence of measure. And what does this instrument accomplish? It records the voltage of the current in short circuit, *i.e*, as measured directly, unimpaired by any obstacle, without body resistance, and is hence merely a deceptive snare for physiological or therapeutic purposes, as the tissues permeated, or character and extent of resistance, which is here ignored, vary the current value in the most surprising manner; for instance, the heavy coil, when in perfect juxtaposition, gives a current of 240 volts by the Edelmann faradimeter, and yet this has but an imperceptible physiological effect when applied through a high body resistance; whilst the fine coil, which, in the same position, indicates only 180 volts, has a powerful effect, and, on the contrary, when applied through a low resistance, as in visceral or bipolar faradization, the intensity and efficiency of the 240-volt current far exceeds that of the 130 volts.

The strength of the current would be far better approximated by indicating the nature

of the coil and the resistance offered than by the volt scale of this faradimeter; yet it is a beginning, and a move in the right direction, not to be confounded with the faradimeter pictured in an American work, to which I should not again refer were it not to exemplify how lightly this subject of faradic electricity has been treated. The following statements are calmly made of an instrument which does not, and did not then, exist: "With this at our command we can observe and record qualities, tension, and volume of the faradic current used upon a patient in terms of the same standard, the volt, and the ampère." As the instrument has not materialized it is needless to call attention to the fact that the *coulomb*, and not the volt and the ampère, is the electrical unit by which we must measure faradic electricity; and that, as I have already stated, even this is no index of its physiological effect.

Most authors have nothing whatever to say of the tension or quality of the interrupted current, and I refer to works which have appeared in the last few years; but one text-book, on "Electricity in the Diseases of Women," does touch upon the subject, stating that "the volt-force of the faradic current *probably* varies from several hundred to several thousand volts," whilst, as a matter of fact, it rarely attains the intensity of several hundred: the volt-force of a shorter coil varies from 10 to 300 volts, with an inducing current of 300 milliampères and 2½ volts; and that of a fine coil from 5 to 180 volts, as Edelmann states.[1]

Hardly more definite are the teachings in our medical works upon other features of faradism. Thus, the subject of current-break, the essential, the very life of this form of electricity, receives but little, if any, attention. One author passes it over with the injunction "to avoid an instrument which makes a harsh noise," and another limits his demands upon the interrupter to "a clear note" as important in gynæcological practice. The variation in the physiological effect of the current by change of interruption, and the complete control exercised over it by a properly-adapted trembler, which I claim to be a prominent feature, has never been alluded to.

When variation of interruption is spoken of, it is within limits which afford no positive alteration of physiological effect, and a definite assertion is never made, the number of interruptions necessary to obtain a certain effect is never given, and no instrument exists in which a *definite number* of interruptions as *needed* for a *definite purpose* can be obtained at will. Rapid and slow interruption is occasionally spoken of, but the reader is left to infer the meaning of these words; but one author, the most scientific, tells the practitioner how to determine the number of oscillations of the trembler by comparison of its sound or note with that of a tuning-fork of known vibration. Yet this knowledge, acquired with such difficulties, is of little value, as it will be almost impossible to again obtain this same number of interruptions, and practically it is of no importance, as the range of possible variation is insufficient for the obtaining of practical results thereby. A single instrument exists, now in the College of Physicians, in Philadelphia, devised and described by Onimus and Le Gros, in which the rapidity of interruption, within moderate limits, can be defined, but it has never been particularly utilized. I will add that, since writing this, attention has been directed to this point, and efforts in this direction have been made by some of the leading workers.

More detrimental to the therapeutic progress of faradism has been the persistent ignoring of the variable physiological effects produced by currents from coils of varying resistance and electro-motive force or different length and thickness of wire: one author, regardless of what was already taught by Duchenne half a century ago, tells us that "all usable strength and qualities of a faradic current are obtainable from a single secondary coil," and even speaks of the "coarse-wire nonsense"

[1] I note these measurements as recorded by Edelmann, and yet I have my doubts as to their accuracy; my own measurements are not as yet completed, and I prefer to give no imperfect data, but will only say this much, that I find higher ampèrage from the heavy coil, and, as far as I can now say, lower voltage; hence I wish it distinctly understood that I am here quoting from Edelmann, and giving the voltage as impressed on his faradimeter.

as something to be eradicated because it is absurd and confusing to the practitioner. I have myself been thoroughly scored for venturing to insist upon the variability of therapeutic effect produced by coils varying in their relations of resistance to electro-motive force, or coils of fine and heavy wire, and, in short, in a comparison of recent medical literature, we are confronted by vague and contradictory statements, mainly theoretical, without a sound physical, physiological, or therapeutic foundation. Thus, quality and therapeutic effect are estimated by the *feel* of a current to the hand or arm of the investigator. It is upon such grounds (Steavenson and Lewis Jones, " Medical Electricity," London, 1892) that the identity of currents from coarse and fine coils is asserted; and upon similar experiments is founded the statements of Edelmann, that static, faradic, and galvanic currents, with like interruption and like force, are identical, which would be true, provided that change of potential, volt, and ampère force were similar,—an impossibility from the very nature of these currents; but, because a single impulse from an approximatively similar faradic and galvanic current cannot be distinguished by the healthy tissues of a blindfolded observer, we cannot assert identity of quality and therapeutic effects. Let such reasoning cease. *Feel* is no indication of quality or effect; the *feel* of the mustard plaster and the same-sized plate electrode with a proper galvanic current is not to be distinguished, nor is that of the slowly-heating cautery point and the galvanic needle, the heated metal and the galvanic plate electrode. And yet, is the character of the agent and the effect produced one and the same?

Even the electrician or the physicist adds to the existing confusion when he seeks to arrange electro-physiological and electro-therapeutic facts in harmony with the elementary laws of electro-physics, unconscious of the fact that the human body does not react like a bar of iron or a coil of wire; that measurement in electrical units is not a measure of physiological effect; that a current of high tension and great quantity may have a minimal physiological effect, whilst a current of low tension and small quantity may act with the greatest intensity; and that even Ohm's law ceases to hold good upon the human body when currents are interrupted with sufficient rapidity.

We can hardly wonder at this unfavorable condition of affairs when every idea of quality and quantity is wanting; when even the effect of the current is doubted or but vaguely acknowledged; when its effect is judged by the *feel* it gives to the hands of the investigator (Steavenson, Edelmann, and others); when it is questioned whether the effect of the current is not mainly suggestive or psychogenic (Electrical Congress, Frankfurt, 1891); when an irritating effect alone is ascribed to faradic electricity (*idem*), or its effect is strictly limited to " conditions which exhibit nerve- or muscle- weakness " (Massey),—in itself by no means a narrow or unimportant field; when the average small faradic box is

advocated as answering all purposes (Frankfurt Congress); and when the choice of a faradic apparatus is deemed of little consequence, and the details, such as character of secondary coil, "can safely be left to the judgment of the manufacturer," and "the clear note of the spring interrupter" is cited as *the one* mechanical detail which requires looking into.

A solution of these complicated questions, and an understanding of the intricate phases of faradic electricity, can be obtained only by scientific research, by physical, physiological, and therapeutic experimentation; indeed, the progressive work of individual investigation is now beginning to lift the veil, yet obstacles of various kinds bar the way to the development of faradic electricity as a satisfactory therapeutic agent: we are under the sway of galvanism, and the recently-introduced alternating current, like all novelties, is detracting from the longer-known forms of electricity; so that we can but trust to the energetic work of those interested in faradic electricity, and to the perception of the profession, that they overcome these influences and accord the proper place to the interrupted current.

It is not a question of the respective merits of these various forms of electricity, as each has its own especial sphere; and that of faradism, though it can never supplant galvanism, is far broader and more important than the profession now take it to be, and that of the alternating current must yet be determined.

II. INDUCED CURRENTS.

Every *change*, be it of *force* or *position*, in a magnetic or galvanic field, gives rise to a current of electricity in a conducting circuit near to, but not in contact with, such field. Currents so produced are called induced currents; they are, as ordinarily developed (unless the change in the inducing force is of infinite rapidity), subject, like other currents, to the law of Ohm, and are gauged by one or the other of the standard units of electrical measure.

Induction currents are of short duration, persisting only during the persistence of the change in the magnetic or galvanic field, the change in the inductor or inducer: and, as their existence is dependent upon a change of force or position, and their intensity co-ordinate with the rapidity or intensity of this change, the potential never for an instant retains its primitive value; it is constantly changing, and never attains a permanency.

A. Kinds of Induced Currents.

In accordance with the kind of force and change in the inducing field we distinguish between magneto-induction currents and galvano- or volta- induction currents.

I. MAGNETO-INDUCTION CURRENTS.

The magneto-induction current is developed by a *change of position* between inducer and induced, between a magnet and a closed circuit, the latter being the secondary coil to the ends of which the rheophores are attached. This is accomplished by rapidly approaching and again removing the induction coil from the magnet, or, as it was more commonly done, by a rapid revolution of the magnet, thus approaching and removing it from the coil, each motion generating a current, but in opposite direction to the other. The strength of this current increases with the strength of the magnet, the rapidity of movement, the number of windings in the secondary coil, and the approximation of the coil to the magnet. This was the principle upon which the earlier rotary, or magneto-electric, instruments were constructed; but as this current is no longer used in medical practice, and, moreover, presents the same general features as the galvano-induction current, we will not elaborate it.

II. THE GALVANO-INDUCTION CURRENT.

The galvano-induction current is developed within a neighboring secondary circuit by a variation in the flow of force in the galvanic field: *one* current is generated by the *increase*, and *another*, in opposite direction, by the *decrease*, in the flow of force. This current increases in strength with the strength of the generating galvanic current in the primary circuit, with the number of windings or lines of force in the secondary circuit, and with the approximation of these circuits,—of the inducing force to the induction coil,—but also with the brusqueness of the change in the flow of force.[1]

The theorist knows, and the practitioner to his regret may have discovered, how greatly variation influences even the direct galvanic current. Whilst a continuous current of 200 milliampères may be applied without pain in gynæcological treatment, when *slowly* increased to that intensity, *rapid* increase is very painful, and *sudden* making or breaking would be almost unbearable. The indirect or induced current, however, owes its very existence to variation of force, and is greatly intensified by the brusqueness of that variation, which reaches its climax in the sudden making and breaking of the current.

As the physiological effect of the current induced in the secondary circuit is proportionate to the rapidity of the variation, or the intensity of the change, in the flow of galvanic force in the primary or inducing circuit, we obtain the most effective induction current by the most rapid and extreme change of force in the inductor; that is, by the sudden change from 0 to the full current-force, and again by the fall from its highest efficiency to 0,—that is, by the instantaneous making and breaking of the current. Gentle variations of the galvanic flow in the inductor

[1] This is true as regards the physiological properties of the current, and to a certain extent as regards its physical properties, although these are not co-ordinate.

do not produce induction currents which affect muscle or nerve, but it is the *brusque*, *sudden* change which does achieve the physiological effect.

III. WHY THE GALVANO-INDUCTION CURRENT IS PREFERABLE.

The effect of the induction current being due to variability of status, the highest efficiency can never be achieved by magneto-electric currents, produced by a change of the relative position of magnet and coil, which can only be progressive, approximative, but never instantaneous; hence, for practical purposes, the galvano-induction current is used, but its efficiency is increased by the plus of a magneto-induction current produced not by actual approach and removal of a magnet, but by the more effective sudden magnetizing and demagnetizing of a soft-iron core, within the coil of the primary circuit, by the making and breaking of the inducing current: thus, two currents are induced in the neighboring circuit or secondary coil. It is known that if an inducing circuit is traversed by *one* current and *another* is induced *at the same time*, its effect is increased thereby if this current is of equal polarity or in the same direction, and diminished if in contrary direction: thus, the magneto-induction serves to strengthen the volta-induction current. The current developed by the making of the galvanic flow—the make or closing current—is contemporary and equipolar with that produced by the approach or make of the magnet,—the current of magnetization,—as the break or opening current is identical with that of demagnetization; hence, the resulting induction is as the united product of the two forces.

B. Medical Currents.

I. FUNDAMENTAL LAWS.

For a more thorough understanding of the current as applied in medicine we must recall the fundamental principles of faradic electricity. The establishment, variation, or cessation of a current produces polarizing effects in a neighboring circuit, as proven by the passing current if this circuit is a parallel wire, or by the magnetizing effect if it is a bar of iron, at right angles; and *vice versâ*, variation, relative or absolute, of a magnet causes currents in neighboring circuits, whose direction, intensity, and duration are *in direct relation* to the direction, intensity, and duration of the *change* in the magnetic inducing phenomena.

A current which is established or approximated causes a current in opposite direction in the neighboring circuit: a current which ceases, is removed, or passes away causes in the neighboring circuit a current or a polarity of the same sense or direction as the one in the inductor. These *induction* phenomena all depend upon a *variability* in the inductor, either of condition or position; they cease as soon as permanency is established, in either form of change. *Direct* induction currents are those produced by the negative variations, cessation, opening, or re-

moval, and are in the same sense or direction as the current or polarity of the inductor. *Inverse* currents are those developed by a positive variation, by establishment, increase, or approach, and are in opposite direction to the inductor.

Self-Induction.—Any variation in the flow of force in a circuit develops a current within its own conductor, and this product of self-induction, the extra-current, is in contrary direction to the producing current, and weakens it. The extra-current of make or close is inverse to the current proper of the circuit, or indirect; that of opening or break is in the same direction as the inducing current, or direct.

Direction.—If an observer be swimming in the magnetic field in the direction of the lines of force, which enter at his feet, the current produced by a variation passes from his right to his left. The direction of a current induced in a circuit by any variation in the flow of force is such that it, at every moment, opposes the movement which produces it: if the flow increase,—approach of the magnet or making of the current, —the induced current opposes its increase and existence; that is, it is in the opposite direction to the current which produces it: if the flow decrease,—removal of magnet or breaking of current,—the induced current opposes the diminution, *i.e.*, it is in the same direction as the inducing current.

The *duration* of the induced current is equal to the duration of the variation in the flow of force which produces it.

The *quantity* of electricity is equal to the variation in the flow of force (independent of its duration) divided by the resistance of the circuit.

II. DESCRIPTION.

We can, then, picture the medical current as follows: a galvanic field, consisting of a loop of wire as primary circuit, through which a current is passing from a battery, B, and surrounding this, but not in contact with it, a turn of wire, C″, as secondary circuit. A steady current now flows through C′ from P to N, which is without effect on C″; let the wire be broken at I, and no current can pass; but if the contact is suddenly made, the circuit, C′, completed by uniting the wires at I, an induction current is produced in C″, at the making of the current in C′, in contrary direction to the primary flow of this force, and this again induces an extra-current co-ordinate with itself in C′; so that we now have in C′ the battery current, weakened by the opposing extra-current; but let the flow of force through C′ continue steadily without change of potential, all induction effects will cease as completely as if no current permeated the inducing circuit. If, now, the current in the primary circuit is broken by disconnecting the wire at I, the potential is reduced and another current is established in C″; this is in the same direction as the inducing current, and, reacting upon C′, establishes an extra-current

in the primary circuit, which is in the same direction as the original battery current. The current in C′, both at making and breaking, is in one and the same direction,—the primary is always a direct current in the same direction, of the same polarity with the inducer,—while that in C″

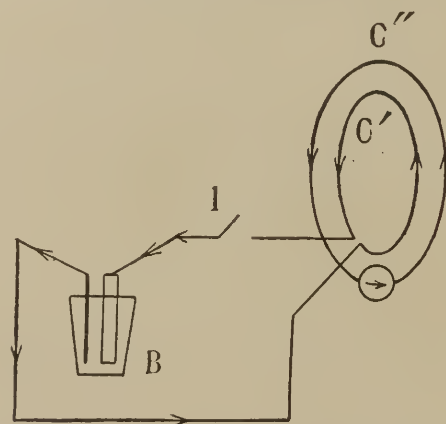


Fig. 1.—Simple Primary (C′) and Secondary (C″) Circuit at Break or Opening of Current.

alternates: at making of the current it is in an opposite direction to the inducing current and the current in C′, an inverse current, and at breaking in the same direction with it, or direct. The flow of galvanic force is feeble, and the magnetic force produced by a single circular turn or wind of wire is small; hence, to increase this force, a number of turns

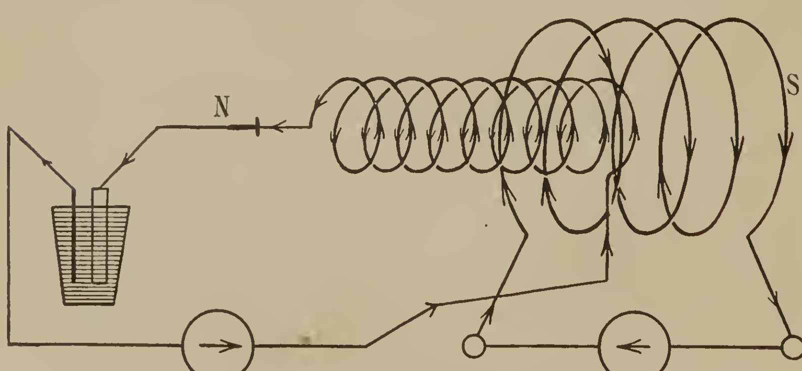


Fig. 2.—Lines of Force Increased by Turns of Wire, Forming a Solenoid Current as Found on Closing or Making of Circuit.

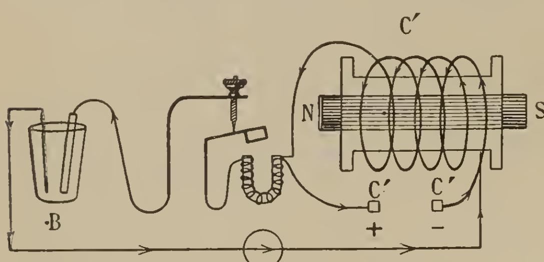
are employed for the primary circuit, C′ (Fig. 2); these are made by the winding of copper wire over a cylinder, and a solenoid is thus formed. The induction force of the secondary circuit is likewise augmented by an increase of the number of lines of force in the concentric superimposed secondary coil.

If we regard the solenoid of the primary circuit as a magnet, as it actually is upon closing of the current at I, its polarity will be such, N—S, that the current induced in C″ opposes its increase and existence by its contrary direction, whilst with the breaking of the current this magnetic polarity momentarily disappears, to be at once re-established in the same direction by influence of the current established in C″ by the break in the primary flow; the break current as opposing the movement of diminution or demagnetization must be one of make or magnetization; hence in the same direction as the original galvanic flow. It appears from this that the currents induced in two conaxial solenoids at making of the current, and making or approach of the magnet, are such that the current in the secondary coil is in contrary direction to the one in the primary, while the secondary current of break and demagnetization is equipolar with it (in the same direction as the primary). Other conditions unchanged, the induction effect is increased by an increase in the change of potential in the inducing circuit,—*i.e.*, in rise and fall of the magnetic force in the primary coil, which can be attained, without increase in battery force, by placing a bar of soft iron within this coil. The lines of force in this solenoid may be likened to those of a long, thin magnet; and if an iron rod is placed within its axis, the lines of force will pass through this rod and magnetize it, and, on account of the greater conductibility of soft iron for lines of magnetic force, they will be concentrated therein, and more lines will then pass through the solenoid than if the iron were not there; practically we utilize a bar of soft iron within the primary circuit, and thus develop more lines of force in the space around the solenoid; we create a more intense magnetic field, and heighten its efficiency. This core, by its successive magnetization and demagnetization, on make and break of current, acts as an inductor upon the two surrounding conaxial circuits, and acts in the same sense as the primary galvanic current. Moreover, it serves, in the simpler forms of apparatus, alternately as magnet and neutral body to an iron spring-head, which causes the opening and closing of the battery circuit, thus acting as an automatic interrupter, by means of which the most effective and physiologically active induction currents are obtained from the primary galvanic flow: the variability in the flow of force, which produces the induced current, thus attaining its limit, as the most abrupt increase and decrease of current and approach and removal of magnet is obtained by the sudden making and breaking of current and magnetizing and demagnetizing of core and solenoid.

The fluctuation of force in the *primary* circuit acts not only upon the neighboring secondary coil, but reacts upon itself (self-inducing),—a reaction which is greatly augmented by the increase in the magnetic powers of the circuit by the core of soft iron. These currents, resulting from self-induction, are called extra-currents, and, from the laws enounced,

it is evident that the extra-current of make, or magnetization, is opposed to the primary current of make, and weakens it so much that it may be disregarded, whilst that of break, or demagnetization, is co-ordinate with the battery current, and is as a plus to the flow of force in the primary coil at break; hence, although make and break currents in the primary coil are both direct, in the same direction as the battery current, the latter preponderate to such an extent that we take account only of the current of break and demagnetization.

The *induction* currents proper, in the *secondary* coil, are quite different in character; the inverse current, induced by closing of circuit and make of the magnet, takes effect as well as the direct current of opening and demagnetization. Although these currents are alternating, in opposite direction, it is customary to attribute one direction, or polarity, to them, which is always that of the current of break, or demagnetization, as its intensity and physiological effect is far greater than that of the make current, though equal as to quantity. The curve of the direct or opening current is more brusque, the variable stage to which it owes existence being more brief than that producing the make current; hence its greater physiological efficiency. We now have this condition of affairs (Fig. 3): 1. A galvanic current sweeps around the primary coil, C′, which (*a*) converts the core into a magnet, N–S, and (*b*) induces a momentary reverse current in the secondary coil, C″. 2. The sudden magnetizing of the core itself induces a reverse current in the secondary coil, which strengthens the galvanic induced current within this circuit. 3. The magnetized core attracts the soft-iron head of the spring to itself, and so breaks the current-flow. 4. This stopping of the current-flow stops the magnetizing influence upon the core, and a direct current is induced in the secondary coil by the breaking of the primary current, strengthened by that induced by the demagnetization of the core. 5. The magnetic force holding the hammer being removed, it returns, by the tension of the spring, from the core to the battery-wire, whereupon another current passes, and by these vibrations the process is repeated in such rapidity as the strength of spring and magnet admits.



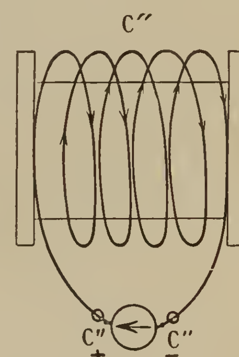


FIG. 3.—FARADIC APPARATUS, SHOWING CURRENT OF MAKE AND MAGNETIZATION.

III. CHARACTERISTICS.

The faradic current, although the product of induction, is an electric flow with all the properties of the electric fluid, which vary in degree only in three forms in which it is employed in medicine, as galvanic, static, and faradic electricity, and we may now add, as a fourth, the alternating current. The faradic, which resembles the lately-introduced alternating current, being, as it were, an intermediate between galvanic and static, is characterized by the brusqueness of its curve, and by its variability, interruption, and alternation, as compared to the constant and continuous galvanic, with less quantity or ampère force than this, and higher ampèrage, though less voltage, than the static. The galvanic current, as used in medicine, has great quantity with low voltage,—from 1 to 300 milliampères, with from 2 to 40 volts; the faradic has less ampèrage and higher voltage,—$\frac{1}{100}$ to $\frac{1}{10}$ milliampère, with from 10 to 250 volts. The static has a minimal quantity, not over $\frac{1}{1000000}$ ampère, or $\frac{1}{1000}$ milliampère, and the highest voltage, from the hundreds upward. The alternating current is used by Apostoli with from 32 to 64 volts. These conditions may be graphically demonstrated by the flat, voluminous curve of the galvanic current, the abrupt, brusque curve of the faradic, and the still more abrupt ascent of the static. Yet the properties of the fluid in these various forms of its application remain unchanged as those of water, whether flowing in the broad channel of a stream, hurled in jets from the nozzle of a hose, or escaping as steam from the valves of a boiler.

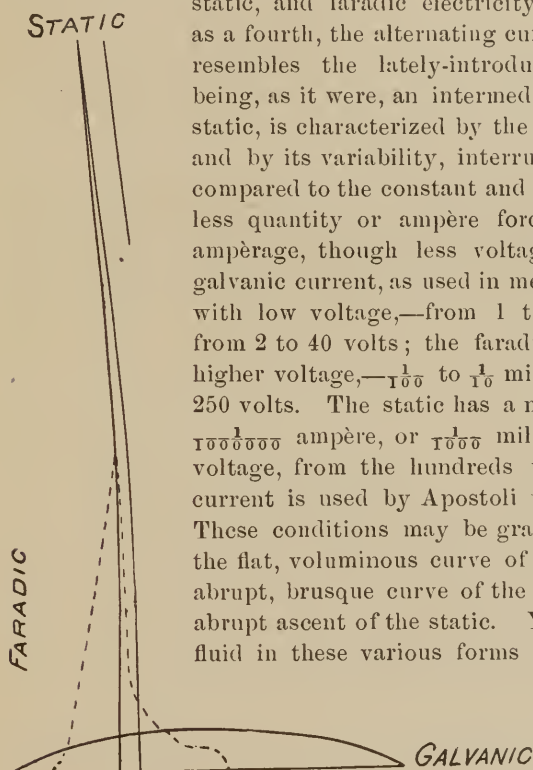


FIG. 4.—CURRENT CURVES.

The curve of the primary current differs greatly from that of the secondary, as it differs in measure, sensation, and physiological effect; sense or direction, duration and intensity of both currents is well represented by Fig. 5 (Edelmann), which shows us the primary flow, M N, alternately made and broken every second; a b, b c, c d indicate the duration each one second, whilst a f, b g, c h represent the intensities of primary (battery) flow.

On make or closing of the current, at the beginning of the second a b the primary flow is inauguarated, attains the intensity a f, at which it continues until the opening or break at the close of the second b, when it suddenly sinks to 0. To this current are added the extra-currents of the primary circuit, on make, at a, an extra-current in a contrary sense, reducing

the force of the original flow at f, and at b, break, in the same sense thus strengthening the flow at g. This make and break of the primary flow induces the contemporary current impulses A, B, C, D, in the secondary circuit; the less-powerful impulse, or current of make, A, C, being in a contrary sense to the primary flow, whilst the break current, B, D, which practically is alone to be considered, is in the same direction.

The primary flow continues whilst contact persists, but the secondary lasts only as long as the change of force in the primary flow on make and break, and its intensity is proportionate to the intensity of the primary as influenced by its extra-currents at the moment of make and break.

In speaking of the faradic current it is virtually the opening current, the current of break and demagnetization, which alone is considered, as it is the preponderating element in both primary and secondary coil, and determines polarity or direction, as well as intensity, of the

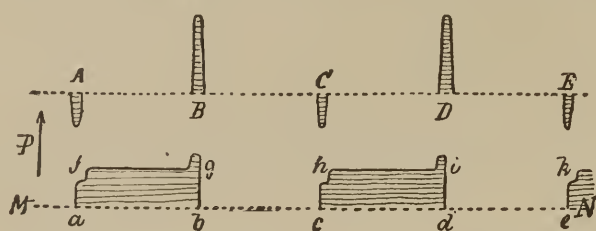


FIG. 5.—SECONDARY AND PRIMARY CURRENTS. (EDELMANN.)

currents. In the primary circuit the closing current is reduced by the induced extra-current, which is in the same direction as the opening current, and aids it so that the opening current is the sum of the induced electro-motor force, and that of the inducing circuit itself, with a greater quantity of electricity, as indicated by the galvanometer, and with greater physiological effect. For the secondary coil the galvanometric quantity of electricity, as measured on short circuit, is the same for both opening and closing current; but as the physiological effect of the former is greater, it is the opening current alone which is considered; this is of shorter duration, and, the same energy being expended in a shorter time, is of higher tension, and its effect on muscle and nerve is greater; it is the controlling factor, as far as physiological and therapeutic purposes are concerned, and is alone considered, to the exclusion of the make or closing current.

The opening current is formed and completed in about 0.000275 second, and the closing current in 0.000485 second, the ratio of potential being as 6 to 13 for a current of this character. The duration of the current of opening is shorter, its curve more brusque; its tension and power to overcome the body resistance encountered in all therapeutic applications is greater, and this preponderance over the closing current

increases with the increase of resistance. With large moist electrodes, or in the electric bath, the physiological effect of opening and closing current is the same: this is with lowest resistance, as we see also the identity of physical effect in the sway of the galvanometer needle when resistance is 0. As resistance increases, the preponderance of the opening current steadily increases, until with the highest possible resistance, as in the high-tension, single-wire current, we cease to see any effect from the closing current, whilst that of the opening current is marked. So in physiological effect, and the same is true of the high-tension current in physical effects, a flash lights up the electric lamp on opening, whilst no result is visible on closing. With more moderate resistance the deflection of the galvanometer needle proves to the eye this preponderance which the sense of feel readily discovers. The resistance of the body varies with the tension of the current, being less as the tension increases, less for the faradic current than for the galvanic, and varying likewise for the faradic itself; less for the fine coil than for the coarse coil, and less for the current of opening than for that of closing; only when the body resistance is reduced to a minimum do we find an equality of physiological effect in the currents, but this is a condition rarely attained in medical usage, with the exception of the faradic bath. The more brusque curve of the opening current is well demonstrated by the spark, which is larger on opening than it is on closing of the circuit, although produced by the same amount of electricity; the same energy is expended in a shorter time, and produces a greater effect. This spark, which serves no purpose but to convey the extra-current of opening to the primary coil, consumes a large percentage of the current-energy, of which some 25 per cent. is lost, much of this being converted into heat in the spark.

The actual current-energy is indicated by $I \times E$, or the current-intensity multiplied by the electro-motor force,—the number of windings in the coil (always remembering that E is actually $E - E'$, as we shall see later); in the secondary current it is only three-fourths of that in the primary. Like opening and closing current, so anode and cathode vary in physiological effect: the *cathode*, or negative pole of the faradic current, has a greater effect on motor and sensory nerves, and can always be recognized thereby. The closing contraction will be first observed at the cathode, the opening contraction at the anode. Weak currents contract only at closing in both directions of the current; moderate currents show a stronger closing than opening contraction, and very strong currents contract only at opening with ascending currents, and at closing with descending currents. The effect of the poles on sensory nerves is similar: whilst the closing contraction may be said to be cathodic and the opening contraction anodic, both poles have a certain sensory influence, but the closure (cathodic) excitation is greater than the opening (anodic) excitation.

The difference in the effect of the poles, like that of opening and closing current, increases with the resistance, and here also we see the most striking difference in the high-tension single-wire current, a bright glow being obtained from the negative pole, with the positive grounded; but if the 118-volt lamp is connected with the positive pole, and the negative is grounded, the light is more dim and intermittent or flashy. Coils of high electro-motor force are necessary for these experiments.

IV. VARIATIONS.

The faradic current is a most pliable and variable form of electricity, subject to changes (*a*) in *intensity* and *quantity* and (*b*) in *quality*, by alteration in the current-giving apparatus and in the method of application, thus making it possible to obtain a variability of physical and physiological effects and giving it great therapeutic possibilities.

(*a*) *Variations in the strength of the current* are of two kinds, either in physiological effect not measurable, or in quantity, as indicated alike by measure and effect. The first, obtained by insertion or withdrawal of the tube of Duchenne, by variation in the rapidity of the contact-breaker and by variation of resistance, I will not here discuss, as it is of little importance compared to the last, the now universally-adopted sledge movement of the secondary coil. The tube is used only in small pocket-instruments, and, while varying the shape of the curve, does not alter its size, a diminution of intensity being accompanied by a corresponding increase in the time of the discharge, and *vice versâ;* so that the product, Q, or quantity, which is always equal to $I \times T$, remains unchanged. Change of resistance varies the effect of the current and its quantity in a given manner, being inversely proportionate to I; yet the rheostat would be an unnecessary addition and unsatisfactory for measuring purposes, and the influence of varying body-resistance upon the faradic current is hardly to be considered as a means of varying the current-effect. Surface-resistance, determined by character of electrodes as well, and also the number of interruptions, vary the strength of the current, but they likewise vary its quality, and should rather be considered under that head. As the influence of the interrupter as a controller or influencer of current-strength is an entirely new feature, I will briefly outline this method.

The current-strength, or rather its physiological effect, is gradually though slightly increased by an increase in the rapidity of interruption up to a certain speed of the contact-breaker, and then diminished by increase in the rapidity of interruption. We see this exemplified by Coil III, short, 1458 winds, 79 ohms resistance, as follows: with high resistance, small metal electrodes to upper and lower arm, the first sensation on single impulse is not experienced until 45 of the scale; whilst a slow beat, 150 per minute, is felt at $40\frac{1}{2}$, and the more-rapid interruption, 4000

per minute, is already felt at 34. Muscle-jerk is obtained at 63 on single impulse, at 52 with slow interruption, and at $43\frac{1}{2}$ with rapid. The greater the current-strength, the greater the number of interruptions necessary to reduce the current to 0, or to annul its effect on the sensory nerves; but before this point is reached the muscle ceases to respond, a rapidly-interrupted current, to which the muscle no longer reacts, still influencing the sensory fibre.

A moderate current, such as that from Coil III of the Engelmann battery (W. & B.), at 45 of the scale (or $\frac{1}{3}$), is sufficient to produce muscular contractions with 45 to 1000 interruptions per minute. This current grows stronger with an increase in the rapidity of interruption up to 4000 per minute, then soon decreases,—muscular contractions cease; at 6500 sensory nerves almost cease to react,—a current effect is barely perceptible; and before 10,000 is reached it ceases to be felt altogether. If the current is a strong one, as it is from the fine Coil III completely overlapping the primary, with an inducing force of 4 Leclanché cells, and applied through large, moist electrodes, a current too strong for ordinary therapeutic applications, the number of interruptions necessary to reduce its physiological effect to 0 must be greatly increased; but if pushed to 28,000 per minute, even this strong current will not be felt, whilst at 25,000 it is still perceptible. The rapidity of interruption controls the physiological effect of the current as perfectly as the sledge movement of the secondary coil; so that, all other conditions unchanged, it is an index of current-strength, and might be used as such with well-regulated interrupters.

To demonstrate this current gradation by variation in the number of interruptions I will cite a single experiment. Coils I and III of the Engelmann battery are used, with an inducing force of 300 milliampères and 5 volts (on short circuit, about 75 and 60 volts, respectively, by single impulse), applied by moist electrodes, three by four inches, to upper and lower arm, giving a moderate resistance (3000 ohms), which almost determines equality of coils:—

NUMBER OF INTERRUPTIONS PER MINUTE.	COIL I.		COIL III.	
	FIRST SENSATION.	FIRST DISTINCT MUSCLE-CONTRACTION.	FIRST SENSATION.	FIRST DISTINCT MUSCLE-CONTRACTION.
	Position of Coil on Sledge Scale, in Millimetres. from Point of First Contact.			
1600	5	15	5	22
3500	10	20	15	25
6500	15	25	25	30
11000	20	30	27	34
13200	27	35	32	35

Whilst not actually applicable for purposes of measurement, this table will serve to show the importance of the contact-breaker and the necessity of noting the number of interruptions if any distinct idea of current-strength is to be obtained, and it is self-evident that, for the regulation of current-intensity, the type of apparatus hitherto in general use must yield to more perfect and accurately-constructed instruments which admit of a regulating and recording of the interruptions.

Variations in the quantity of the induced current, comparable to the galvanometric measure or value, are obtained by the sliding of the secondary coil over the primary. This is the method in general use for the regulation of current-intensity. Its mechanism is simple; the current-strength is readily seen by the position of the coil, and noted by the scale marked on the sledge. The electro-motor force is indicated with approximate precision by the arbitrary divisions of that scale, as it is nearly proportionate to the distance between the centres of the coils. This method of varying the current-strength has been long since adopted, and has served for record by the placing of a scale on the slide; and we can now appreciate its advantages over other methods more fully, since we know that this change of position indicates a change of force which is measurable, and that its galvanometric measure corresponds more nearly with the physiological efficiency of the current than do changes of other kinds.

(*b*) *Variations in Quality.*—Of the greatest importance to the medical man are the variations in quality and physiological effect of the current; so much so that I may say that upon this factor depends the therapeutic value of the induction current. These current-changes, by which the most varied therapeutic results can be obtained, are produced by variation in the secondary coil, in the rapidity of the contact-breaker, and in the extent of surface-resistance. Whilst the current-strength is likewise varied more or less thereby, this is of minor consequence, and, as we have in the sledge a method superior in every way to attain this end, I shall consider only the essential feature, variation of physiological effect or quality. Each element is characterized by an individuality of action, and must be separately described; and yet, in proper combination only is its highest efficiency and the greatest variability of physiological effect obtained. Thus, the short secondary coil of heavy wire is characterized by its effect upon muscle, especially the muscular fibre of internal parts, where the resistance is reduced to a minimum; but this is by no means true under all conditions and for all purposes, and to attain its greatest efficiency in this direction the coil must be combined with low surface-resistance and slow interruption of the primary flow. The long coil of fine wire is characterized by a sedative and anæsthetizing effect, but this is only with diminution of surface-resistance and great rapidity of interruption; with moderate interruption and high surface-resistance its action is quite to the contrary,—revulsive. Whilst great

rapidity of interruption determines a nerve-quieting effect of the current, this is only true of currents from long, fine coils, and applied with low surface-resistance; thus, we must utilize the different means of varying the current-quality to attain the most perfect results, yet each acts independently of the other and in a manner peculiar to itself.

The secondary coil greatly influences the physiological effect of the induction current by variation in length and thickness of the wire used in its construction,—that is, variation of resistance and number of winds,—upon which quantity and electro-motor force, or tension, of the current depend. These are the features which influence its characteristics most decidedly, and not whether it be from primary or secondary coil, as Duchenne supposed, who observed the effect correctly, but was misled in his reasoning. We now know that effects which he obtained from the primary coil, and naturally attributed to it, were due mainly to the character of that circuit, and are very similar to those produced from a secondary coil of similar character, and that the apparently peculiar effects of the secondary coil are due mainly to the fact that this was always constructed of longer and finer wire. The distinction he makes between primary and secondary coils holds good if we consider the primary as a short, heavy, and the secondary as a long, fine coil; hence we have little need of the primary circuit, since we can obtain the same variation of effect more satisfactorily by placing a similar coil in the secondary circuit.

Unquestionably there are some differences of physiological effect between primary and secondary coils, but these are not of sufficient importance for therapeutic purposes as long as we have only the one small primary coil. Until we can obtain a greater range of primary coils, such as I have in connection with a specially-constructed instrument, it is far better that we confine ourselves to the secondary circuits, which admit of comparison and of extensive variation.

The primary circuit, if properly constructed, has a special therapeutic field, from which I have already obtained admirable results; but I am not yet prepared to discuss them, and they are unattainable from ordinary faradic primaries; hence I will not dwell upon these currents. From Duchenne's own statement we see that primary and secondary are practically coarse and fine wire, or low and high, electro-motive-force currents. The five main points of difference between primary (coarse) and secondary (fine) coils made by Duchenne are: 1. The current from the secondary (fine) coil acts more intensely on the retina, if applied with moist electrodes to face or eyeball. 2. The secondary (fine) coil affects the sensibility of the skin more intensely. 3. The primary (coarse) coil affects organs more or less deep under the skin more intensely. 4. The secondary (fine) coil produces more marked reflex contractions. 5. If moist electrodes are used on the skin, the secondary (fine) coil penetrates deeper than the primary (coarse).

I have considered only the striking variations of current as produced by changes in the secondary coil. Upon length and diameter of the wire depends the resistance of the coil and the quantity of the current; the number of windings or turns determine the electro-motor force; hence these details must all be given in defining character and effect of a current, and every coil should be accordingly marked. A short coil of heavy wire is indicative of great quantity or ampèrage, and low tension or electro-motor force; a long coil of fine wire, of small quantity and high tension; each factor has its significance, and it is a mistake to give all importance to the number of turns of wire, or lines of force, as some have done, claiming that a coil of heavy and one of fine wire will have the same effect, provided that the number of windings are the same in each, basing this assertion on the "feel" of the current and the idea of an equality of lines of force, without physical or physiological experiment, and forgetful of the important element of resistance, as varied by thickness of wire. As a matter of fact, the current from two such coils differs in quantity and quality, in galvanometric measure and in physiological effect,—yes, even very much in *feel*. Let us examine two coils:—

Heavy: No. 15 wire = 0.85 ohm resistance, 528 windings.
Fine: No. 40 wire = 180.00 ohms resistance, 528 windings.

The heavy coil preponderates in quantity, or ampèrage; the fine in tension, or voltage. At 100 of the sledge scale, the coils overlapping, the heavy coil gives, on short circuit, a galvanometric force of 25 milliampères, and the fine coil only 0.5 milliampère, or one-fiftieth; with 3000 interruptions per minute (high resistance, 50,000 ohms) and metal electrodes applied to middle of upper and lower arm, the heavy coil causes strong contractions, not at all painful at 100, perfect juxtaposition; whilst the fine coil could not be borne at that point of the scale, and is very painful at 75, yet causing very slight contraction only, the heavy coil producing strong contraction at 50, without any sensation. With moist electrodes two inches square, in the same position, and a resistance of 7000 ohms, the heavy coil causes powerful contractions at 70, with almost no perceptible feel of the current; whilst the fine coil causes strong contractions at 40, yet so painful that they cannot be borne beyond 50. The current from the fine short coil, 528 winds, is an exceedingly sharp one, affecting the sensory nerves, whilst the heavy coil affects these but little, yet acts powerfully on muscle.

Surface-resistance, kind of electrode, and rapidity of interruption greatly vary the current from coils of all kinds, affecting each one differently, so that the effect of a coil cannot be wholely defined without a knowledge of the conditions under which it is used; yet, as a rule, I can say that the short, coarse coil, low resistance, with greatest possible electro-motive force, by prolonged application renders the parts more sensitive; even after a *séance* of ten minutes the current must be reduced to avoid more powerful effects, whilst the current from the long, fine coil,

high resistance, and high electro-motive force, is sedative in its effect, and quickly establishes a certain tolerance; this anæsthetic effect increasing with number of winds, thinness of wire, and rapidity of interruption. In a vagino-abdominal application for reduction of pelvic pain the fine coil was distinctly felt at 35 volts, short circuit, with 3500 interruptions per minute, and after an application of five minutes was moved farther over the primary to 50 volts before it was even felt.

With low resistance, as it is not generally met with in medical use, though decidedly marked in the electric bath and in some bipolar applications, the current from the short, heavy coil is stronger and of greater physiological effect than that from the fine coil; as the resistance increases the fine coil gains ascendency, and with the high resistance usually found it is stronger by far, with greater physiological effect, than the coarse-coil current. Even in the spark we observe the marked difference in effect; the spark from the shorter, heavier coil is shorter, but hotter, from proper instruments giving sufficient heat to melt iron; from the long, fine coil it is longer, but gives less heat.

In a bipolar intra-vaginal treatment with an inducing force of 300 milliampères and $1\frac{3}{6}$ volts, 2500 interruptions, the shorter coil, 2300 winds, No. 28 wire, produced painful sensations at 110 volts, short circuit; whilst the longer coil, 8200 winds, No. 40 wire, was not even felt at 150 volts, *i.e.*, in more perfect apposition with the primary. With 400 milliampères inducing current, a heavy coil of 1100 winds, 3.8 ohms resistance, and fine coil, 11,050 winds, 1030 ohms resistance, high circuit resistance, faradic brush on elbow and hand, the fine coil is intense at 11 centimetres from complete juxtaposition, whilst the heavy coil is not even painful when full in: but if large, moist electrodes are used, the coarse coil at its weakest gives intense and painful contractions, whilst the fine, full in, is painless and the contractions produced are but slight. The less the resistance the less the preponderance of fine coil, until with minimal resistance the coarse coil is strongest.

This weakening of the current is not due to a resistance measurable in ohms, but to a counter-current produced by self-induction; it is a diminution of potential, and not an increase of resistance. The opening current induces a counter-current in its own conductor, and thus prevents the ascending; this counter-current does not change the quantity or the galvanometric effect, and the surface of the curve remains the same at the initial and maximum intensity, but its apex is very much changed. This self-induced counter-current is stronger in the fine coil and stronger with low resistance; hence these peculiar phenomena. The law controlling self-induction currents is this: that they increase in intensity (1) with approach of the circuits, more intense the nearer the circuits, hence greater in their own conductor than in a neighboring circuit; (2) with diminution of diameter of the wire in the coils, hence greater in the fine-wire coil; (3) with strengthening of the current, hence

greater as resistance is less or battery force greater. By self-induction the potential of a fine coil of 1030 ohms resistance through a body-resistance of 3000 ohms is reduced to only 22 per cent. of its original value, whilst that of the heavy coil is diminished much less, remaining at 78 per cent. of its original value.

The electro-motor force cannot be measured simply by the number of winds (Weil), but it is E—E′, E′ being the electro-motor force of the counter-current. According to the nature of the coils their relative strength varies, but for the average extremes of coarse and fine coil equality of current effect at the same point of the sledge is obtained at a body-resistance of from 1000 to 3000 ohms (see experiment, p. 137, showing almost equal effect of coarse and fine coil with variable number of interruptions at 3000 ohms resistance); but with metallic resistance this equality of current, as measured, is obtained at from 200 to 300 ohms (Weil); so that we may see how greatly current effects are varied by changes in any of the determining conditions, and it is evident that the variations of current obtained by differences in the construction of the secondary coil are of the greatest therapeutic importance, and must be recognized by manufacturer and practitioner before efficient instruments and satisfactory results are obtained.

Having found that the highest possible resistance with the lowest possible electro-motor force produces the most painful, irritating currents, and the lowest resistance with the highest electro-motor force the most powerful muscle effect with the least pain, I have improved on the former coarse coil of 0.8 ohm resistance and 528 winds by a coil of fine wire in multiple, giving 6500 winds with 4.1 ohms resistance, and thus obtain the best contractile effects. The most useful coils for general nerve and penetrating effects are with 4000 to 6000 winds, but sedative effects superior to those from such coils I have obtained from coils of 9600 and even 12,900 winds, with resistance up to 2500 ohms. Experiment has shown me the peculiar physiological effects of the differently-constructed coils, and I hope soon to be able to determine precisely and accurately the conditions for various coils, under which they are most efficient for their especial therapeutic purposes.

Rapidity of interruption likewise varies the quality and physiological effect of the current greatly without altering the galvanometric value. The effect of the contact-breaker is such that the strongest currents from the fine coil, in complete juxtaposition, with moist electrodes, can be reduced from a maximum intensity, insupportable to the sensory nerves, to 0, and with such regularity of gradation that *the number of interruptions may serve as measure of current-strength.* Yet I utilize the interrupter merely for the variation of quality or kind of effect; slow interruption, from 5 to 200 or 300 per minute, determining more effective muscular action, whilst the sedative effect upon sensory nerves is more readily secured by rapid interruption,—20,000 to 50,000 per

minute. A current which, with moderate rapidity of interruption, produces powerful muscle-contraction with marked sensation is gradually reduced as rapidity increases, the contractions cease, and it is scarcely felt when the number of interruptions is increased still more; finally it is completely obliterated, yet produces a sedative and even an anæsthetic effect, though no longer recognized by the sensory nerves; this anæsthetic effect persists for a greater or less space of time, according to intensity of current, rapidity of interruption, size of coil, and length of sitting. Coil III, 32 wire, 6000 winds, 650 ohms resistance, at 45 of the scale, with three by four inches moist electrodes and an inducing force of 4 Leclanché cells, produces muscular contraction with 1000 interruptions per minute, and is not felt with 7000, yet produces a sedative anæsthetic effect establishing tolerance; at 100 of the scale, the coil full in, the current is too powerful for motor or sensory nerves up to 15,000 interruptions, but with 25,000 it is scarcely noticeable, and yet produces a decided sedative effect. Rapidity of interruption, while strongly influencing the physiological effect of the induced current, does not in itself control this as completely as it does when combined with the proper quantity and quality of current and surface-resistance; that is, with suitable coil and electrode, each in itself influencing the nature of the current in a similar manner and approximating the same results.

In brief, I may say, of the contact-breaker, that the physiological effect of the current slowly but distinctly increases with the number of interruptions, from 1 up to 2500 or 3000 per minute; if the current be a mild one, it reaches its highest intensity at 3000 to 4000, then decreases, at about the same rate, until no longer felt with from 7000 to 9000 interruptions. The muscles respond less acutely than do the nerves; very slow interruption, of moderate current, is perceived by the sensory nerves only; as rapidity increases muscular fibre contracts; with greatly-increased rapidity the muscle ceases to respond, and finally the sensory nerves; so that with great rapidity the current is no longer perceived, and yet physiological effects are produced, though the current is *not felt.* The greater the current-strength, the greater the number of interruptions necessary to completely annul its effect. Slow interruption favors muscle-contraction and rapid interruption nerve effects; the very rapid, whether perceived or not by the sensory nerves, is sedative in its action.

Surface-resistance, as produced by character and material of electrodes and moisture or dryness of skin, determines intensity, also quality and effect, of the current, the latter being the important therapeutic factor: moist electrodes, low surface-resistance, render the current painless and penetrating without effect upon the superficial sensory nerves, yet acting with energy upon deep-seated muscles; the cotton-covered electrode, thoroughly saturated with fluid, reduces both surface- and tissue- resistance; the dry epidermis is saturated, its conducting powers

greatly increased, and its resistance reduced; perfect contact is established, the entire surface of the electrode is available, thus lessening the density of the current to a minimum, rendering it painless and causing it to penetrate; the same current, from the same coil, might be arrested upon the surface with revulsive effect, causing great pain in the superficial sensory nerves. This radical change in the physiological effect of the current is produced by a diminution of surface-resistance, the highest resistance, a painful surface-current, being produced by the dry metallic electrode placed loosely upon the skin, the smoothest penetrating current by the moist electrode pressed firmly against it.

A secondary coil of 32 wire, with 4500 feet, 747 ohms resistance, and a current of 400 milliampères, applied with *high* surface-resistance, small metal electrodes, to the middle of upper and lower arm, 500 interruptions per minute, is intensely painful at 50 of the scale, so much so that it could not be borne stronger; applied in the same place with *low* surface-resistance, by the moist electrodes, two inches square, even with the utmost intensity of current, with coils overlapping, at 100, strong contractions were produced, but no pain. The metal electrode with this coil at 50, half in, powerfully affects the sensory nerves, motor nerves barely responding, whilst the moist electrode is hardly perceived under these conditions; and if the current is increased by the moving forward of the coil to 100, strong muscular contractions are produced, but still the sensory nerves are little affected. Thus, it is evident that surface-resistance, character of electrode, and method of application vary the physiological effect of the current, as Duchenne has long since taught. A revulsive effect is produced by high resistance, dry skin, and metallic electrode, whilst the penetrating, deep nerve and muscle effects are from moist electrodes, with low resistance; especially quality and physiological effect is altered by variation of surface-resistance, quantity and galvanometric measure being less affected. The primary electro-motor force unchanged, we vary the intensity of the induction current by the sledge movement of the secondary coil, and its quality, or physiological effect, by variations in the character of the secondary coil, in the number of interruptions, and in the amount of surface-resistance, as determined by character of electrodes, never relying upon any single one of these factors, but combining these various methods of current-variation to achieve the desired result.

V. MEASURE AND RECORD.

The absence of definite galvanometric measure is another of the unfavorable conditions which have served to retard the therapeutic use of faradism. As the study of the induction current by the galvanometer affords no indication of its physiological action, and as up to the present time we have no means of determining a unit of physiological efficiency, we must content ourselves, for purposes of measure and of record, by

defining the conditions under which the current has been developed, and the manner of its application.

It is impossible to compare satisfactorily currents from all medical instruments, by reason of the great difference in construction, especially those in which gradation is one of physiological effect only, without change in any measurable quantity. Uniformity of record and a definition of current-strength can be attained only in the sledge instrument, in which the galvanometer effect, like the physiological, decreases with the removal of the secondary coil from the primary, and the extent of separation of the coils is an approximate gradation; hence, I shall consider only currents from instruments of this kind, which are in every way superior for medical purposes.

The measurable element in the induced current is its *quantity;* we cannot properly speak of its intensity, nor can we value it in ampères; we can estimate only its quantity, the product of time and intensity ($Q = I \times T$), which is expressed in *micro-coulombs* and is measurable. The same is true of the condenser discharge, as we may see by the experiments of Edelmann, who finds a condenser discharge of 9.8 volts in 261 millionths of a second as effective, physiologically, as one of 70 volts in 70 millionths of a second of time, the increase in time serving to make 9.8 volts as effective as 70; but peculiar difficulties likewise oppose the measurement of this form of electricity, as volt-force is lost when passing off under low potential, the more being lost the lower the potential.

The opening faradic current is measured by sending it into an electro-dynamometer and noting the maximum deviation given by this impulse to the needle, then comparing this with the discharge of a condenser of one micro-farad capacity, charged to the potential of 1 volt, therefore containing one micro-coulomb, which, upon my instrument, is 3.95 divisions of the scale. To measure a given induction flow the shock of the opening current, obtained by pressure upon the single-impulse key, is conveyed to the electro-dynamometer, and the number of degrees obtained, as marked by the greatest deviation of the needle, is divided by 3.95, the product being the number of micro-coulombs, or the current quantity. We can now indicate the galvanometric value, by noting the quantity of the opening impulse in micro-coulombs upon the scale for every change of position of the coil—this being true for a fixed inducing current—for one given coil and for a certain resistance. Moreover, it is necessary that every opening impulse be alike, which is possible only by an even-working contact-breaker, as it is made, but not found in the average instrument for the more-rapid interruptions.

The scale so graded as to indicate in micro-coulombs the quantity of current for a certain resistance is, at present, our nearest approach to measure; and this resistance must be a body resistance, as the current-energy varies differently for metallic and for body resistance; the maxi-

mum intensity for metallic resistance being attained at 0 or complete overlapping of coils, and at 3 centimetres for body resistance. Even with attention to these details this is deceptive and the scale only an illusory one, as the physiological effect varies with conditions ever present in therapeutic applications, which in no way affect quantity.

Granting that the inducing current remains unchanged, the physiological effect varies with the resistance of the circuit and its variable elements, these being the metallic resistance within the coils themselves dependent upon length and thickness of wire, and the external resistance, size and character of electrodes and body resistance proper, in itself a most unstable element, varying for opening and closing current, varying for different points of the scale, and varying from one moment to the other with the change of potential.

A single experiment will illustrate the extreme variation of current-strength and effect caused by change of resistance, and also the variation of that resistance by apparently trifling causes. Coil I, 0.85 ohm resistance, 528 winds, with an inducing current of 400 milliampères and 5 volts, applied by metallic electrodes, 2 centimetres in diameter, to right shoulder and calf of left leg, with dry skin, presenting a body-resistance of 50,000 ohms, is hardly felt at 100 or complete overlapping of coils; the electrodes are held in place by a spring, pressing them down firmly; the surface becomes red, congested, and moist, so that within ten minutes, without change of any kind, leaving electrodes in place, the current is distinctly felt at both anode and cathode at 47 of the scale, less by over one-half, and is almost unbearable at 100, where but a few moments ago it was barely perceptible. This remarkable change of current effect is caused by reduction of surface-resistance, due to thinning of the skin by compression, and its saturation with moisture by perspiration through prevented evaporation and congestion of vessels. If we now reduce the resistance still more, to 3000 ohms, and apply the same current, through large moist electrodes, three by four inches, to upper and lower arm, we find muscular contraction at 27 of the scale at 100 interruptions per minute, at 29 with 6000 interruptions, but no sensation, and at 47 powerful contractions, without effect upon the sensory nerves; and this coarse coil of 0.85 ohm resistance predominates over the fine coil, 40 wire, 180 ohms resistance, 528 winds, which with high resistance gave far the stronger current.

The experiment is instructive in many ways, but here cited especially to demonstrate the variation of resistance within a few minutes, without change of any kind by the operator, the electrodes even remaining in precisely the same place. More striking still are the greater physiological effects of currents of small quantity and low tension over currents of great quantity and high tension: the latter from a fine coil of 6500 winds, with a primary force of 300 milliampères, 5 volts, 5000 interruptions, and 13 micro-coulombs of opening impulse, produced only a distinct jerk with

no disagreeable sensations, whilst the heavy coil, with 528 windings and less than 4 micro-coulombs, produced strong and painful contractions. This is with low resistance, under the less-frequent conditions of application: the opposite effect would be observed were the test made with the high resistance generally found in faradic treatment.

This striking result is due (Dubois, Stauffer) to the influence of the extra- or self- induced current of opening, within the secondary coil,

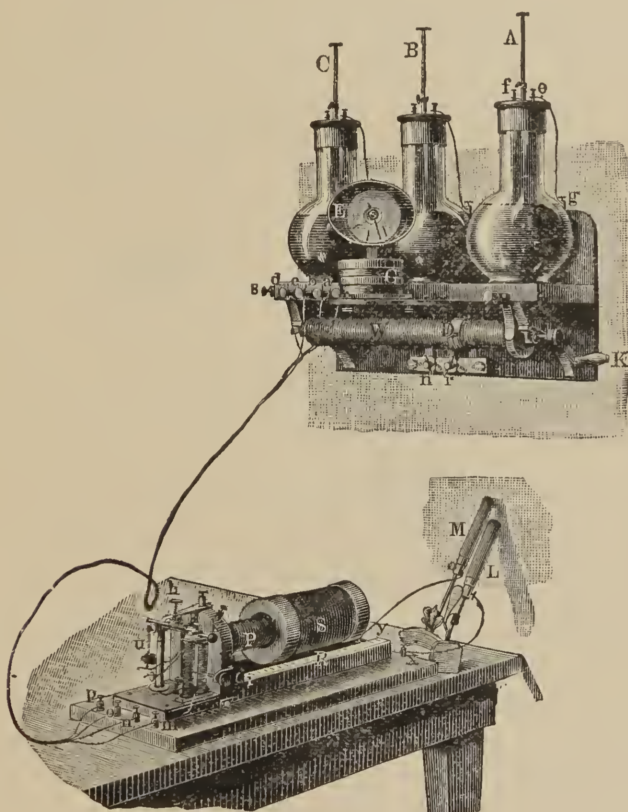


FIG. 6.—EDELMANN FARADIMETER.

upon its own coil-current. The self-induced current is, in opposite direction to the current proper in its own circuit, more effective than the current circulating in a neighboring circuit, and, being in opposite direction, it prolongs the variable stage of the original current which establishes it, prolonging its duration at the expense of its tension, without altering quantity or galvanometric measure; as these self-induction effects increase with the number of windings and the thinness of the wire, the co-efficient of self-induction is much higher for the fine coil, and the current is counteracted far more than in the coarse coil,

being practically 0 in Coil I (Engelmann), 0.8 ohm resistance; hence its greater maximum intensity with less quantity and greater physiological effect on nerve and muscle.

Even less indicative of physiological effect than the gradation of the scale in micro-coulombs is that of the Edelmann faradimeter (Fig. 6) in volts, which is only for a given coil, with a given inducing flow on short circuit, but fails when body-resistance is interposed. The instrument consists of two parts: the stand with the Grenet cells, *C*, *B*, and *A*, with rheostat, *W* and *D*, and galvanometer, *G*, attached to the wall, and the faradic apparatus some distance away, in order that the galvanometer may be removed from the magnetic influence of the iron core within the primary coil. The cell *C* supplies the motive power for the current-interrupter independent of *B* and *A*, which give the current for

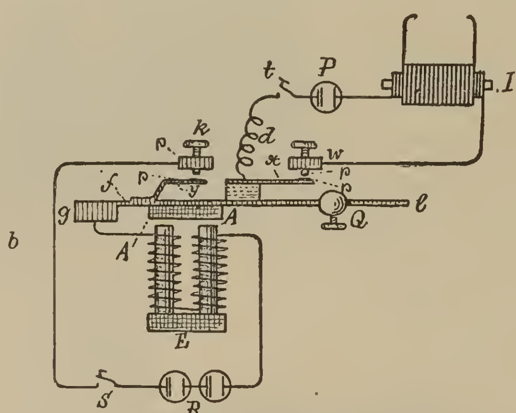


Fig. 7.—Course of Current in Edelmann Faradimeter and in My Instrument, with Separation of Coil and Interrupter.

P, battery for coil; *I*, coil; *E*, hammer-magnet; *B*, battery for hammer.

the coils; this primary current must be one of 300 milliampères, in order that the position of the secondary coil may always indicate the correct volt-force of the secondary induction current, as marked on the scale, *R*, of the sledge.

I use but one Grenet cell, and even this gives a stronger current than necessary, but, by the nickelin-wire rheostat, *W* and *D*, through which it passes, it may be reduced to the necessary intensity of 300 milliampères, which is verified by the galvanometer, *G*, through which the current may be sent at will by pressure on the spring-head, *S*, now and then during the *séance*. The force of the primary flow is controlled by testing the galvanometric effect.

Fig. 7 shows the current interrupted by a separate and distinct vibrator as it is in the Edelmann faradimeter, in my new instrument, and as it should be in every accurate instrument for medical work.

The cut (from Edelmann) likewise shows the hammer of Wagner-Neff clearly as an individual feature, propelled by its own separate battery power, whilst usually it is acted by the coil current. *P* is the battery supplying the current for the coil, *I;* the circuit is closed at *t* and interrupted at *p* and *p* by the hammer of Neff. The hammer, or trembler, itself is operated by the battery, *B*, from which the current passes through the electro-magnet, *E*, then to the anchor or bar of the trembler, *A*, and the spring, *y*, which makes and breaks contact with the governing screw, *k*, the spring being set so that contact is established at *p* and *p* when no current passes. As soon as a current is established by closing the circuit by the key, *S*, the soft-iron horseshoe magnet, *E*, is magnetized, acts as an electro-magnet, and attracts the bar, *A*, breaking the current at *p* and *p;* the current broken, *E* is demagnetized and the trembler, *A*, is released, returns, and re-establishes contact, thus making and breaking the current at both points of contact, *p* and *p*, both for the hammer current and the coil current; yet there is no current connection between these two points, as the contact-breaker for the coil is superimposed upon the bar of the trembler, *A*, but insulated from it, so that the current from *P*—the coil current— is made and broken as often as the trembler, *A*, completes a vibration, yet the currents are separated by the insulating block. My own interrupter differs somewhat from this, and my controllable high-speed contact-breaker is upon an altogether different principle, with this one point of resemblance only,—that the motive power for coil and trembler is separate and distinct, whilst in all other instruments now in use it is one and the same battery-force which supplies both, and contact is made and broken by a spring alternately attached to and flying back from the electro-magnetic coil core as it is magnetized and demagnetized by the make and break of contact.

By the separation of the contact-breaker we avoid loss of power and the self-induction action of the electro-magnet upon the coil current.

The quantity of the current is dependent upon (1) the galvanic inducing flow and primary coil; (2) number of winds of secondary coil and thickness of wire, or coil-resistance; (3) position of coil on sledge; (4) resistance of circuit, but in order to determine therapeutic or physiological effect we must know (5) surface-resistance or character of electrodes and skin; (6) number of interruptions and time of application. The only measure of effect we now have is a record of the details of current production and method of application, and this enables us to value the character, strength, and effect of the faradic current with some degree of precision.

The following points I deem necessary for determination of current effect and for record:—

1. Strength of galvanic inducing current.

2. Character of secondary coil, number of winds, and resistance of coil.

3. Resistance of the circuit, of body, and electrode.

4. Character and size of electrodes determining density of current, pain, and penetrating power.

5. Position of secondary coil on the sledge scale.

6. Number of interruptions of the contact-breaker, approximatively at least, until instruments of precision are furnished.

7. Duration of the *séance*, or time of application.

The first of these, the primary flow, is the only permanent one of the various elements upon which the current effect depends; so that it is evident how difficult it is to obtain a precise estimate of current-energy or physiological effect, since quantity proper, as expressed in micro-coulombs, conveys only a partial and imperfect idea of its value. But, in order to make even this record possible, it is necessary that the manufacturer should construct the apparatus with precision, and that each instrument should carry upon its face an index of force; character of primary coil should be given, and each one of the series of secondary coils must indicate number of winds and resistance of wire; the number of interruptions of the variable contact-breaker, at different points, must be marked; and electrodes should be made in standard sizes, and in proper relation to each other; uniformity in electrodes, primary coil, and galvanic inducing flow would greatly facilitate record and comparison.

VI. EFFECT; METHOD OF ACTION.

The effect of the faradic current upon the human system varies greatly with the character of the current (force of primary flow, nature of coils, and rapidity of interruption), the nature and size of electrodes, and the resistance offered by the body itself; in general, I may say that its action is either irritating and stimulating or sedative, contracting or relaxing, and that this effect of the current, upon any part or organ of the body, is produced by its action upon the controlling nerves and muscles; but in what manner the effect is exercised I cannot positively say. This is as yet an unexplored field. The mechanical action seems prominent; whether or not it acts in other ways as well I am not prepared to state with any degree of certainty. We know that the faradic current can produce chemical changes, as is proven by the spark and its action even upon the invulnerable platinum; but as the polarity is constantly changing, the action of one current is counteracted by that of the next, so that the effect can be but momentary, and nascent chemical products rarely combine; so that a permanent effect can hardly be attained. The chemical effects produced are greatest in currents of greatest quantity from heavy, short, secondary coils, and of slow interruption, becoming quite marked when the closing current is eliminated, as in the one-direction current of the Stöhrer instrument, and likewise in the primary circuit. I do not believe that the chemical effect takes any part

in the action of the faradic current upon the system, but that this is a certain mechanical influence upon the molecular composition of the organism, prominent in its dynamic action (Stein). Boudet cured facial neuralgia by the vibrations of a tuning-fork, 200 per second, communicated to a sounding-board, upon which was fixed a small rod with ball end, which was placed upon the face at the point of exit of the infra-orbital nerve, thus communicating the vibrations to that nerve; after an application of from five to six minutes the pain ceased for a time, and by continuation of the treatment a permanent cure was achieved. I do not rely upon the one statement, but find this indication of the curative therapeutic effect of mechanical vibrations corroborated by the experience of others both in England and in France, and quite recently Charcot's investigations have given a renewed impulse to this medicine *vibratoire:* in the Salpêtrière a large tuning-fork, placed upon an extensive sounding-box, was used, the atmospheric vibrations produced thereby acting as did the rod in the other case, and with similar satisfactory results, even to the restoration of muscular activity in the paralyzed lower arm of a hemianæsthetic.

I fully agree with Stein, who believes that in the mechanical vibratory action of the faradic current we must seek the cause of its physiological action; but as to the idea expressed, that many electro-therapeutic effects are due to a regulation of molecular vibrations, I can say nothing. The question is still an open one, and must be solved ere faradism can be accorded its proper place in medical therapeutics.

C. Medical Uses.

Faradic electricity is used in medicine for purposes (1) of *diagnosis* and (2) of *treatment*, but the range of its utility has been limited by reason of the prevalence of galvanism, our limited knowledge of faradism, the absence of measure and means of comparison, and largely by the crudeness of the instruments furnished, which give but a certain form of induction current, to which therapeutic applications must, of course, be confined, making it really useful in a comparatively small number of cases only. It is impossible to compare galvanic and faradic currents as therapeutic agents, as each has its proper sphere, and that of the induced current will be greatly enlarged with increased knowledge and greater precision and variation of current.

We speak of the positive pole as the anode and the negative as the cathode, which may always be recognized by its sharper current and greater effect on motor and sensory nerves. The prevalence of the negative over the positive pole is more marked for short, heavy coils than for long, fine coils, and likewise more marked when applied through low resistance than through high resistance. Using Coil I,[1]

[1] In speaking of Coil I, II, or III, I always refer to the standard coils of my apparatus as manufactured by Waite & Bartlett, because these are the only coils which are precise as to quantity and quality; number of winds, resistance, length and diameter of wire being noted.

with low resistance, 2500 ohms, both hands in warm zinc-water, 4000 interruptions per minute, the negative pole is first felt at 25 of the scale and the positive at 31; the first contraction is secured by the negative at 44 and by the positive at 50. With Coil III, 1500 feet, and the same conditions, the first sensation is observed at 12 at the negative pole and at 21 at the positive, the first contraction at the negative pole at 26 and at the positive at 31. If we take a high resistance, though only 5400 ohms, we find less difference in positive and negative for Coil I, and with Coil III, 1500 feet, the negative pole is first felt at 22 and the positive at 23, the first contraction or muscle-jerk, for both positive and negative, being noted at 31, whilst for Coil III, 4500 feet, positive and negative vary even less.

I. DIAGNOSTIC USES.

The faradic current is valuable diagnostically for determining the existence, the increase or decrease of pathological excitability, in differentiating between central and peripheral lesions, and in the detection of simulation. In gynæcological practice it is of prominent diagnostic import in differentiating between abdominal and more especially ovarian pains of an hysterical and those of an inflammatory character. The fine coil or tension current with its sedative influence has a potent calming effect on hysterical suffering, especially in abdominal and ovarian regions, and serves an admirable purpose in differentiating between nervous or hysterical pains of the ovary and those which are inflammatory; this means of differentiation, recently emphasized by Apostoli, should be more frequently resorted to, as many a patient is subjected to operation for ovarian pain of a purely hysterical nature, which would have been detected and relieved by the faradic current, had it been properly tested.

In faradic exploration a careful comparison must be made between the healthy and diseased side, or, what is less advantageous, between the part in the diseased and the same part in a healthy person, and repeated investigations are necessary before a positive result can be reached. For scientific exploration we must know the resistance of the tissues on either side, size and resistance of electrodes, number of interruptions, and character of coil and current-strength,—which we are as yet unable to give, but which, for purposes of record and comparison in one and the same case, the primary-battery flow remaining unchanged, is indicated by the relative position of the coil on the sledge scale. The irritability of the muscle is tested by determining the lowest power of the faradic current which will contract it, and then comparing this with the healthy side. It may be noted that in hysterical paralysis electro-contractility is generally normal while electro-sensibility is lowered, and in infantile paralysis voluntary contractility is increased whilst faradic contractility disappears; so also in the reaction of degeneration, or when by an injury,

a cut severing its continuity, the nerve is destroyed, and more or less atrophy or degeneration is found in both muscle and nerve. Even with the crude instruments of former days the variability of reaction in healthy and diseased tissues was well characterized and the faradic current a valuable diagnostic agent; so that we may now expect still more from this current, so thoroughly controllable as it is by the new apparatus.

II. THERAPEUTIC USES.

Even in the secondary position still occupied by faradism it has a broad range of application in medicine and is used in a variety of ways: (*a*) applied to the body direct; (*b*) in faradic massage; (*c*) in the faradic bath.

(*a*) *The direct application of the current*, with both poles in contact with the body, is the usual method of therapeutic use of induction currents, as general, as localized or polar, and as bipolar faradization.

General Faradization.—The labile application, over the entire surface of the body, so earnestly advocated by Rockwell, is used as tonic and stimulant in constitutional debility; above all, in nerve-exhaustion, and as a powerful irritant in cases of asphyxia, suspended animation, and poisoning.

Localized faradization, as Duchenne termed this new departure in electro-therapeutics, the application of the current by one pole direct to the part to be affected, is the method most generally used, and should more correctly be spoken of as *polar* faradization, in contradistinction to the bipolar method and the polar method of galvanization, which is precisely the same manner of application in the use of the galvanic current. This localized or polar method of application has done away with the former distinction between ascending and descending currents; but we still speak of labile and stabile currents, one of the electrodes being moved over the surface, or both stationary, and of superficial and deep, or penetrating, currents,—the former with the dry metallic electrode to the dry skin and superficial nerves, the latter with moist electrodes to the deep-seated tissues. These are the ordinary methods of its therapeutic use: as nerve and muscle irritants in all kinds of paralyses, heart-weakness from various forms of poison, as stimulant in cases of constipation, vesical weakness or relaxation of nerve- or muscle- fibre in any part, and as sedative in neuralgias, in hysterical and inflammatory pains; the short coil of fine wire serving as the most powerful irritant with the dry electrode, the long coil of fine wire having the greatest penetrating power, and with very rapid interruption of current the most marked sedative effect, readily producing tolerance and a certain amount of anæsthesia. The short coil of heavy wire, with slow interruption, produces the most effective muscular contractions, but, instead of producing tolerance, seems to render the tissues more susceptible.

The Bipolar Method.—The bipolar method is the localization of the

current by means of a single electrode carrying both poles, and has of late assumed prominence by reason of the able and energetic work of Apostoli and the efficiency of the methods devised by him in uterine and pelvic disease. It is restricted almost wholly in use to the inner parts, the cavities and mucous membranes, and is practically the application of localized electrization to internal organs; since the current, to be localized or confined to these parts, must of necessity be applied by means of a single electrode; as so little space is given, a metallic rheophore only is admissible, and this can be used effectively for penetrating currents on the mucous membranes, which offer a very low resistance, not to be compared to that of the dry skin, and for this reason, as well as the absence of the numerous sensory nerves, it causes much less pain than would a metallic electrode upon the skin,—indeed, no pain at all. Currents of quantity for muscle effects, and currents of tension as nerve stimulant or sedative, can both be used to advantage, and without causing pain.

Our knowledge of faradic electricity and the means of varying and of applying the current have improved so that the principle long upheld, that for external faradization currents of tension are most active and that in internal, bipolar or localized, faradization the current of quantity acts most vigorously, can no longer be followed as a fundamental rule. Although it is true that currents of high tension penetrate deeper where the resistance is great, as upon the skin, and that the current of quantity is strongest if the resistance is very low, yet it is wrong to generalize and to refer the current of tension to external and the current of quantity to internal faradization. Some of the best therapeutic effects of tension currents, such as the relief of ovarian and pelvic pains, are achieved by their internal use, and equally striking results of quantity, or coarse-coil currents, are obtained in external application, as for purposes of massage or direct muscular contraction.

The advantages claimed by Apostoli for the bipolar method in internal applications are (1) that it is more simple, requiring no assistant; (2) that it is less painful, the sensitive skin being avoided; (3) that it is more active, as localizing the full effect of the current used upon one small part; (4) that it is more efficient, as it admits of the use of stronger currents by reason of the lessened sensibility.

(*b*) *Faradic Massage.*—Under this term, which I look upon as a misnomer as it is now used, is generally understood the combination of faradization with massage: the heightening of the stimulating or sedative effect of massage by a corresponding faradic current applied by means of the same apparatus by which the mechanical effect is exercised upon the tissues, be it hand, or plate, or roller electrode. This I should call a combination of massage and faradization, whilst I term faradic massage proper the stimulating or contracting of the muscle by faradic currents of quantity and slow interruption,—the most efficient of all means of muscular stimulation or massage, as it can be applied directly to any desired muscle

or group of muscles, and stimulates the tissues by arousing heightened natural action.

I will not elaborate this now, but will speak merely of faradic massage as generally understood, a most agreeable and effective method of treatment. The effect of massage, which has been established in our country by the earnest efforts of our honored colleague, Dr. S. Weir Mitchell, and his successful treatment of neurotic, bedridden women, is increased by the use of a properly-modified current, galvanic or faradic, as the case may be. Thus, the absorbing action of the hot baths of Hot Springs or of Wiesbaden is heightened by galvanic massage, and the sedative and stimulating action of tonic waters or treatment by faradic massage.

The *galvanic* current *alone* causes a more permanent hyperæmia without the disadvantage of the mechanical irritation of massage, and, on the other hand, it lacks the advantages of the mechanical effect,—the removal of stagnating blood and lymph; both together, properly applied, re-inforce each other, the galvanic current making the effects of massage more lasting. The rules for application are the same as for simple massage. The method of action is well stated by Mordhurst as follows: (1) the hyperæmia caused by massage is heightened and prolonged by the contemporaneous application of galvanism, and this heightened effect is achieved without the injurious influence of too intense mechanical irritation, as severe and long-continued massage would produce it; (2) by massage with the massage electrode the absorbed particles of the pathological product, taken up by the lymphatics, are mechanically removed from the diseased site; (3) the long-persisting hyperæmia in the skin aids greatly in the depleting of the morbidly-affected lymphatics in the neighboring tissues.

Galvanic massage is especially adapted for the treatment of articular rheumatism and the removal of indurations and inspissated deposits, but it is also used for the relief of neurasthenia and neuralgic pains.

Faradic massage augments the stimulating effect of massage, and by the penetrating powers of the current extends its range of action to the deeper tissues, without adding to the superficial irritation; the calming, sedative effect of the mechanical manipulation is likewise increased by the direct action of tension currents upon the nerve-fibres. Faradic massage is useful in various forms of nerve-exhaustion, neuralgias and headaches, in chlorosis, in paralysis, constipation, muscular rheumatism, and in certain phases of chronic articular rheumatism. Although generally applied by a current from the ordinary battery, by means of the plate or roller massage electrode, Butler uses an apparatus of his own construction, in which the generator is within the roller itself.

(*c*) *The Faradic Bath and Douche.*—Both faradic and galvanic currents are used in hydro-therapeutic treatment, and are combined with

bath or douche, as the electric bath and the electric douche, and are used in very much the same class of cases as electric massage, though more general in its effect. The manner in which the bath is given varies with the construction of the tub, whether this is of a conducting material or not. If the tub is of metal, generally copper, the patient must be protected from contact with its walls by a lath-work of wood : one rheophore is connected with the tub itself, and the current is thus carried by the water to that part of the body which is immersed, the other electrode being applied to a part out of the water. More commonly a tub of non-conducting material is used; porcelain is best, but wood, coated with white, non-metallic enamel, can be used, and is cheaper. The current is generally passed lengthwise through the body, the back or shoulders resting upon the non-conducting protector of the one plate and the feet against the other; some use a larger plate at the head end, but others (Trautwein) merely coil the terminal of the battery-wire a few times in this electrode and use a large plate at the foot end; for some conditions the current is directed more to certain parts by small plates placed accordingly. Back and feet rest against the protecting, non-conducting rim of the electrode, about one and a half inches from the plate itself; it should not be too far away, in order not to diffuse and weaken the current, as water, unless very warm, opposes far more resistance to the current than does the body. The resistance of water as pleasant for a warm bath is but a trifle greater than that of the body with the epidermis saturated, and at 30° R., or 38° C., a hot bath, the resistance of water and body is the same; so that the current-measure is the same, whether passing in the bath through the water alone, or through water and body in the tub.

It is said that about one-sixth of the current passes through the patient (Steavenson), the saturation of the epidermis diminishing the resistance greatly, so that from a galvanic current of 200 milliampères the patient receives 40 milliampères. This diminution of resistance, which is, of course, readily shown by actual measurement, is further marked by the equality of closing and opening induction current in the faradic bath, and by the inefficiency of tension currents from fine secondary coils, which have almost no effect; hence the primary coil is used for bath currents, or, better still, secondary coils of very heavy wire.

The important features in determining the result are: temperature of bath, kind and intensity of current, and time of application. Plain water is used, to which solutions are often added, but the mineral waters of health resorts are preferable. From ten to fifteen minutes is amply long for a first bath; this is increased in time with the staying powers of the patient, but should rarely exceed thirty minutes. It is well to begin with the body temperature of 98° F., gradually increasing or decreasing as the case may demand. The strength of the current used will depend upon the necessities of the case, but, as the time of application

is prolonged, it should never be very strong; the faradic current must, however, be distinctly felt, and the galvanometer must be consulted for the galvanic bath, as with the diminution of surface or skin resistance, and the large surface of application, low density of current, it may produce but little sensation, yet a powerful constitutional effect.

The *faradic bath* is the perfection of general faradization and the direct opposite of localized electrization, the confining of the effect to the diseased part; as it is frequently used to intensify the action of curative mineral waters, it is found in its greatest perfection in watering places; the faradic current, thus used, in combination with a bath of proper temperature, is a most agreeable sedative in neurotic cases, and a pleasant as well as efficient stimulant in general debility, as from anæmia or neurasthenia, and it is most unfortunate that this useful agent should be more or less relegated to quackery. In place of being conscientiously applied by skilled hands, under proper conditions, we find it in public establishments, handled by an ignorant attendant, and given to whomsoever pays for it, or, worse still, it is a money-making agent for the advertising quack. In many instances the effect is, of course, pleasant and satisfactory; but if the patient be sensitive, or the case one contra-indicating the bath or the current, the innocent seeker after health may be carried away unconscious, or may receive a shock from which it will take him or her days to recover. This useful remedy should be developed, and restored to the realms of legitimate medicine.

The *faradic douche* is an equally valuable agent in its proper sphere, as a general application, in neurasthenic cases, and locally used in uterine and spinal diseases. The douche proper, hot or cold, is used as the rheophore, or conductor, to carry the faradic current, by which its efficiency is greatly augmented: A large plate electrode is applied as the indifferent pole to a near surface of the body, and douche or spray, of proper temperature, is thrown from the fluid-carrying rheophore, at a distance of six to twelve inches, upon the part to be reached. It is an admirable application in spinal weakness, and as a sequence to the bath, or alone, in neurasthenic cases, producing a pleasant tingling feeling and a healthy reaction; so also the cold spinal douche is given in or after the hot bath, and the tonic and astringent effects of the uterine douche can thus be augmented by the faradic current.

III. APPARATUS FOR THE PRODUCTION OF FARADIC CURRENTS FOR MEDICAL PURPOSES.

A. Essential Features of the Apparatus.

The elements necessary for the production of faradic currents are (*a*) a flow of galvanic force; (*b*) the primary circuit or coil; (*c*) the strengthening core; (*d*) the automatic interrupter; (*e*) the secondary

circuit or coil; (*f*) an appliance to vary the current-strength without change in the flow of galvanic force.

I. THE GALVANIC INDUCING FORCE.

Galvanic currents of small quantity and low tension are used in the production of faradic electricity, averaging from $1\frac{1}{2}$ to 5 volts and from 200 to 1500 milliampères, those of highest ampèrage having the lowest voltage and *vice versâ*, the Leclanché cells with lower ampèrage having a higher voltage. The current-producers vary with the instrument. Those most commonly used are (*a*) the sulphate of the binoxide of mercury cell, which is extremely convenient for the pocket-battery, as the dry powder, being in small bulk, can be readily carried about in a bottle within the battery itself. The carbon forms the receiver or cup within which the salt is dissolved in a little water, the zinc being placed into it after stirring; a single charge gives a flow of force sufficient to supply the instrument for the longest *séance*. (*b*) The small bichromate of potash cell: either upon the principle of the Grenet cell, or, as it is frequently used in the portable box-battery, carbon and zinc in one cup and the fluid in a second, well sealed with a rubber cork, so that it can be poured into the empty cell when it is to be utilized. For the stationary or sledge instruments we generally use (*c*) the Grenet cell, giving a current of $1\frac{3}{5}$ volts and $1\frac{1}{2}$ to $2\frac{1}{2}$ ampères, which is convenient, as it is ready for use as soon as the zinc is dropped into the fluid; but objectionable on account of the acids employed, the fluid being a solution of bichromate of potash and sulphuric acid. Preferable is (*d*) a couple of two Leclanché cells, in which the harmless muriate of ammonia filling needs but the addition of a little water once or twice in a year, if evaporation is prevented by a well-fitting cover. Sometimes three or four are used (two suffice for many purposes for some instruments), giving a current of about $2\frac{2}{3}$ volts and 250 milliampères.

The Gonda-Leclanché or the permanganate of potash cell—in fact, any couple of one of the numerous similar elements, with harmless fluid and cover to prevent evaporation—is most suitable, as the current is established as soon as the circuit is completed, the apparatus being set in motion by a turn of the switch.

II. THE PRIMARY CIRCUIT.

The primary circuit, always stationary, is, as we have seen, a solenoid consisting of a number of turns of well-insulated copper wire, wound in regular layers upon a hollow cylinder of non-conducting material, wood or hard rubber, with the zinc connection inside of the coil. Wire of moderate thickness and length is used, frequently No. 22 wire, 0.7 millimetre in diameter, so that as little resistance as possible is opposed by the conductor itself to the primary galvanic flow; and yet it

must admit of sufficient electro-motive force to push the current through the long secondary coil; though it cannot be too thick, so as not to occupy too much space. This primary coil must be proportionate to the battery-force employed; the magnetism produced by the solenoid in the core being proportionate, as long as the customary small magnetizing force is employed, to the intensity of current and the number of windings of wire; but after a certain force is reached the increase in magnetism becomes less marked and tends more and more to a limiting value, which is greater for soft than for hard iron or steel.

Too many windings or lines of force render the instrument bulky and decrease its power. The large sledge instruments of Edelmann and Waite & Bartlett have a primary coil of 22 wire (0.7 millimetre in diameter) in from 4 to 6 layers, with from 200 to 400 turns; smaller instruments are made with coils of fewer turns and often thicker wire, giving a sharper current. The large instrument of Gaiffe has a primary coil of 0.7 millimetre wire with 1150 turns, forming a spool 19.7 centimetres in length by 3.8 centimetres in diameter,—shorter than that of Edelmann and longer than that of Waite & Bartlett. This circuit is always closed unless opened by the interrupter; but if the primary or direct extra-current is to be utilized, it is switched off at the extremities of the coil to two binding-posts, from which it is taken, thus forming a branch circuit which is generally open, and closed only by the object through which the primary current is passed, when this is to be utilized.

III. THE CORE.

The strengthening magnetic core, by which the magnetic force of the surrounding solenoid is increased, depends for its efficiency upon its conductivity; that is, the rapidity with which it is magnetized and demagnetized, the rapidity of variation or change of potential determining the physiological efficiency of the current produced.

A bar of soft iron was placed within the hollow of the primary cylinder, projecting a little at either end, beyond the cavity of the spool; soft, well-heated iron was employed, as this material is magnetized and demagnetized most readily; yet disturbing induction processes, or eddy currents, were found to take place within its mass, which led to a loss of power, so that it was supplanted by bundles of well-heated soft-iron rods carefully insulated. Spirals of wire are also used; and the core of the Engelmann instrument consists of a sheet of soft iron, as thin as paper, rolled into a cylinder, which seems to magnetize and demagnetize more readily, and also to give a more satisfactory physiological effect than the wire core. This core may be fixed or movable, made so as to be wholly or partially withdrawn, or it may be covered by a movable copper or brass tube. This brass or copper cylinder, *the tube of Duchenne*, made to slide between core and primary coil in the pocket-battery, and between primary and secondary coil if used in a sledge instrument,

but, as a rule, found only in small instruments of simple construction, is used to vary the strength of the current. The method is simple, yet unsatisfactory, as the presence or withdrawal of the tube weakens or strengthens the physiological effect of the induced current without changing its quantity, and weakens it but imperfectly.

The presence of this tube acts as a damper on the magnetic forceps of the core by interfering with the lines of force from the coil to the iron core by counter-currents which they themselves produce in the cylinder, and thus the opening or break current is modified in its intensity. With the opening of the current in the primary coil two currents are induced, one in the copper cylinder and one in the secondary coil; both have the same direction and induce in the other conductor a current contrary to the first; the result is that the induced current is hindered in its ascent, the curve is flattened, its physiological effect is diminished, although its galvanometric quantity remains unchanged.

IV. THE INTERRUPTER.

(*a*) *Importance.*—The current-breaker, interrupter, trembler, vibrator, or hammer, as still made in the great majority of medical instruments, is merely the automátic arrangement by which the changes of potential in the galvanic flow, which develop the induction current, are produced in rapid succession, without manual interference, by the successive making and breaking or closing and opening of the primary current, and all that is required of it is a uniformity of action, as indicated by a "clear note" or a smoothly buzzing sound; yet this mechanism—upon which the very being of the faradic current is based—is one of the most important factors of a serviceable faradic apparatus, as, by a variation in its action, all other conditions, such as battery-current and position of coil, remaining the same, the character of the current is changed and its intensity or physiological effect can be varied from a minimum to a maximum intensity by variation in time and phase of the rise and fall of the potential, and also by the rapidity with which rise and fall of like phase succeed each other. In the primitive state in which it is found in most medical instruments it is deprived of all significance but that of a simple interrupter and maker of induction force, all that is demanded of it being that it "do not make a rasping noise or act irregularly."

(*b*) *Number of Interruptions.*—The interrupter as generally made vibrates between thirty and fifty times in the second,—that is, at the highest, about 3000 per minute,—and thus serves to establish an induced current of a certain quality; but as its physiological effect is varied by number and character of these interruptions, and a single trembler rarely admits of sufficient variation, one or more interrupters are attached to the more perfect instruments.

The most satisfactory arrangement we have had is that by which the character of the interruptions can be varied and their number changed at

will: this is attained to a certain degree in the Waite & Bartlett instrument with two interrupters, from 1 to 50 or 60 per second, and in the Gaiffe instrument, with one trembler, only up to 50 per second,[1] and by the single impulse-key, with which each of these instruments is supplied, they can be made at will, by manual pressure, in very slow succession. Simple as this appliance is, and important as it is for purposes of diagnosis and muscular massage or stimulation, it is not found in the average medical instrument.

I regret that space does not permit my entering more fully upon this subject, as my recent experiments demonstrate most unquestionably that the interrupter is one of the most valuable factors in current control and variation, and that the range and utility of the faradic current will be greatly enlarged when instruments with properly-variable tremblers or interrupters are given to the profession; and these must be such that they can be set at will from one to many hundreds per second, must be entirely independent of the galvanic flow which acts the coils, and propelled by a separate and distinct motive power.

(*c*) *Kinds of Interrupters.*—Contact-breakers as now made are of three kinds, (1) the core itself serving as the attracting magnet, or (2) a separate magnet is formed; but in both the battery-current, which serves as inducing force, also determines the magnetizing and demagnetizing of the magnet, which causes the vibration; but (3) in instruments of precision the contact-breaker is an appliance separate and distinct from the induction apparatus, with a motive force independent of that of the instrument proper. I may add (4) the single impulse-key and (5) the rapid controllable interrupter, which must be added to a perfect instrument.

The contact-breaker *in small instruments* and in those of more simple construction consists of a spring with soft-iron hammer-head, platinized, in which the wire of the primary circuit terminates; the force of the spring presses the hammer-head against the other part of the vibrator,—a platinum-pointed screw,—which forms the terminal of the battery wire, thus establishing the flow of force, rendering the core magnetic. The hammer, being placed within the magnetic field, within one-sixth to one-fourth inch from the core, is attracted to this soft-iron terminal, breaking the primary galvanic circuit, whereupon the core is demagnetized, becomes neutral, and releases the spring, which flies back to the battery terminal and the process is repeated. The rapidity of vibration in the average instrument can be regulated, within moderate limits, but not sufficient to determine any marked variation of physiological effect; this is done by the platinum-pointed screw, which controls the length of oscillation by increasing or decreasing the distance

[1] Since writing the above the singing rheotome has been adapted to several instruments and gives vibrations of much greater rapidity; unfortunately, it is not possible to regulate and control these as it is necessary to do for therapeutic purposes, and the vibrations vary with the battery force employed, as the rheotome is not independent of this.

between core, or magnet, and screw-point or battery wire, within which the hammer moves.

In most *larger instruments* of foreign make the attracting force is not the core, but a small electro-magnet entirely independent of it, formed by the coiling of the battery wire around a soft-iron horseshoe; and it is of necessity so, in all instruments in which the battery force is varied by withdrawal of the core, as this must be movable without interfering with the efficiency of the apparatus. This is the ordinary contact-breaker, the hammer of Neef, or Wagner-Neef, which is more or less complicated according to the perfection of the instrument, yet never practically varies the effect of the current. Screw-point and hammer-head are always platinized, in order that oxidation may be prevented and perfect contact may be interfered with as little as possible; the bright spark formed at these points would rapidly destroy other metals, and even the almost invulnerable platinum is gradually coated with a thin film and slowly corroded so that the point of contact must be occasionally changed, and in time, after long use, even the platinum must be replaced. The platinum surface should be cleansed and the delicate film of oxide removed, as it offers a resistance, an obstacle to the passage of the current, which causes loss of power.

Independent Interrupter.—In faradic instruments of precision the motive power for the contact-breaker is supplied by a separate current, independent of that supplying the inducing force: this is a change which I deem important, because I have found that the vibrations of the trembler, in instruments as generally made, are varied by every change in the inducing flow and in the position of the coil, and also on account of the disturbance in the current caused by the self-inductive action of the separate electro-magnet attracting the hammer. In my new instrument, as made by Waite & Bartlett, the inducing current enters the primary circuit directly and is made and broken by the action of the vibrator, which is set in motion by an independent force. This I deem the only method of interruption for a complete instrument, being entirely independent of the coil current proper, as it is acted by its own battery force, and it is a method which can be adapted to every kind of interrupter.

Very slow interruptions are produced by a pressure upon a spring, the single impulse-key, such as is found in the Gaiffe and Waite & Bartlett instruments.[1]

The better instruments are furnished with improved contact-breakers of varying form, some of them having two or three,—rapid, slow, and single impulse,—the slow vibrator varying from 1 to 20 in the second, and the fast spring with from 20 to 60 oscillations per second; the singing rheotome of the Galvano-Faradic and Dry-Cell Battery Company's instrument is a horizontal steel vibrator, far more rapid than the above

[1] Since writing this other instruments have appeared with the single impulse-key, which is a valuable addition.

vibrators when currents of sufficient power are used. Although admitting of rapid vibrations, these vibrations, as already stated, are not sufficiently controllable, and not controllable to a sufficient extent to make this method one which is available for medical instruments of range and precision ; moreover, as considerable battery force is necessary to act this rheotome, the same strong currents which are necessary to act the rheotome must be used for the coil, and mild currents, which are frequently needed in therapeutic applications, are inadmissible.

To attain all the varying physiological effects more rapid contact-breakers, not necessarily vibrators, such as I have suggested and Messrs. Waite & Bartlett have constructed for me, are needed ; these are independent of the primary galvanic flow and controllable, as I consider it to be of great importance that the operator *should know*, approximately, at least, the *number* of interruptions for purposes of scientific research or therapeutic record. The interrupter is arranged so as to indicate, within reasonable limits, the number of oscillations at any given point. This interrupter is a separate instrument, which may serve as interrupter or alternator for galvanic or faradic currents, primary or secondary ; the speed is obtained from the shaft of a motor propelled by a Grenet cell or storage battery, giving 50,000 interruptions per minute, as I believe that 50,000 per minute, 800 per second, is a rapidity sufficient for therapeutic purposes, though I have experimented with interruptions of over 100,000. I have as yet made no therapeutic tests of these highest rates, and have had no more instruments so constructed, as the results of my physiological experiments are such as to lead me to believe, with great assurance, that the most satisfactory therapeutic effects and all necessary current variations are obtainable with interruptions up to 50,000 per minute, and that higher rates are useless unless the make of the induction apparatus is greatly changed ; with instruments as now made 50,000 per minute is an extreme ; any number can, however, be obtained, if desired, and always with precision. The speed indicator, the rheostat, and galvanometer admit of a perfect control of these interruptions.

Observations upon the physiological effect of variable interruption are almost wholly wanting, for the reason that only trifling variations have been achieved by the instruments hitherto furnished, and no index to their number is given, nor can a desired number be attained at will; so that it was simply impossible to record the work done, even within the narrow limits which were allotted. · The only method we have had of determining the number of oscillations of the interrupter was by comparing its note, or its musical interval, with the note of a tuning-fork of known vibration, and even this is referred to but rarely, and used more rarely still ; it is practically possible only to the perfectly-trained musical ear. Each octave has twice the number of vibrations as its key-note, the major third $\frac{5}{4}$, the fourth $\frac{4}{3}$, the fifth $\frac{3}{2}$ the number. (Edelmann.)

V. THE SECONDARY CIRCUIT.

The secondary circuit is that from which the alternating, inverse, and direct current, the induced current proper, as generally used in medicine, is taken; hence it is an important feature of the apparatus. Its force, like that of the primary circuit, is increased by increasing the number of windings, each winding or turn of wire having the same electro-motor force; so that ten windings possess ten times the electro-motor force of one, and in the completed coil we have the added effect of each single winding or line of force. The quantity of electricity passing is, however, inversely as the resistance offered by these windings, the greater the less the resistance; that is, the thicker the conducting wire and the shorter it is, or the fewer the windings, the less resistance do they offer. To be most efficient as an induction-current producer, resistance and number of windings must be in proportion to the inducing force, to the galvanic flow, and the magnetic power of primary solenoid and core.

This circuit, like the primary, is constructed of well-insulated copper wire, coiled in regular layers upon a non-conducting hollow reel, conaxial with that of the primary coil, which fits into this hollow. As the strength of the induced current depends upon the nearness of the inducing to the secondary induction circuit, the layers of the secondary winding must be as near as it is possible, without contact, to those of the primary, which must fit closely into the very thin spool of the surrounding secondary coil, and a limit is placed to the number of layers of its windings,—that is, the thickness of the spool; its length, determining to some extent the approximation of the circuits, likewise influences the nature of the resultant induction current; but, although long spools have their advantage, they likewise have their disadvantage, and the more smooth and pleasant, yet therapeutically effective, currents are developed from the secondary circuits coiled on shorter spools. This interesting and practically valuable fact I cannot explain, but its truth has been proven by repeated and careful tests of the best instruments, with every possible length of coil. Within certain limits, dependent upon the inducing force, the secondary coil should be constructed, in regard to resistance and number of winds, with a view to the physiological or therapeutic result to be obtained,—a feature which, to the great detriment of faradic electricity, is hardly found in any of our medical instruments.

I am not as yet prepared to define positively the most efficient forms of secondary coil for our various therapeutic needs, and will merely say that I am now testing coils constructed in reference to the instrument with which they are to be used, varying in resistance from 0.8 ohm up to as high as 2500 ohms, and in number of windings from 528 to 12,000, with wire from No. 15 to No. 36 and 40,—the finest which can be well insulated.

VI. METHODS OF VARYING STRENGTH OR INTENSITY OF PHYSIOLOGICAL EFFECT.

Every apparatus for the production of faradic electricity must be provided with some means of varying the current-strength without altering the primary galvanic force. The *direct*, *primary* or extra, current is weakened by the withdrawal of the intensifying core, or by a decrease of magnetizing power by the presence of the shielding tube; so that these parts are arranged to be withdrawn or inserted at will; yet many instruments are void of any such mechanism, as they ignore the utilization of the primary current.

The essential feature is the *gradation of the induced* current, and this variation of the electro-motor force in the secondary coil is attained without change in the primary flow by varying the coefficient of mutual induction of the circuits, by a change in their relative position, the approach or withdrawal of core, tube, or secondary coil; the latter being by far the superior method. The object to be attained is the *gradual* variation of intensity, without jarring or irregularity, from a minimum to the maximum of electro-motor force.

The removal of the core or its complete covering by the tube, whilst rendering the current very weak, does not reduce it to a minimum, and would necessitate the addition of a rheostat for thorough control; in instruments in which the core serves as a magnet for the interrupter it cannot be moved, and the tube is a superfluous addition and a detriment, as it increases the distance between core and primary, or primary and secondary circuit, weakening the induction effect. Moreover, the galvanometric or measurable intensity of the current is not altered by removal of the tube, however much the physiological effect is varied. The quantity of flow remains the same, its curve only being changed; hence the tube is used only in pocket-instruments, which must be very compact, cramped into the smallest possible space, which does not admit of a moving to and fro of the large secondary coil.

The only simple and practical method of varying the current is by approach and removal of the outer or secondary coil from the inductors,—primary coil and core,—which are fixed, and thus the induction force can be varied from 0 to its maximum, and the change established with regularity and precision. In the great majority of instruments, and in every more exact apparatus, the gradation of induction force is produced by the sliding of the secondary coil over the primary, and only to those so constructed do I refer in speaking of faradic instruments, as the galvanometric, like the physiological effect, decreases with the removal of the secondory coil; and not alone is the effect varied, but it can be graded, by the extent of separation of the coils, as the electro-motor force induced in the secondary circuit is nearly proportionate to the distance between the centres of the coils. The increase is

very slow until the coils begin to overlap, then the current increases rapidly with the pushing in of the coil; at four centimetres from complete contact the ascent grows less brusque. The increase of electromotor force is less marked with still farther pushing in of the coil; when near the end, at one centimetre, the effect is suddenly much reduced and the increase is still less until contact is made.

Not alone is this the most satisfactory method of gradation, allowing a gradual and regular increase of current and admitting of its utilization throughout the entire range of its electro-motor force, but it admits of a certain definition of current-strength, of record and comparison, by a subdivision of the sledge or slide, at will, in inches or centimetres, so that the position of the secondary coil can be noted as an index of electric force.

The physiological efficiency of the current can also be graded from 0 to the maximum of physiological force by the contact-breaker in properly-constructed instruments, by varying the rapidity of interruption; but this, like the tube of Duchenne, in nowise affects the measurable intensity; although a regulator of therapeutic value, it is useless for purposes of dosage, since the same status of the interrupter has a different significance for different current-intensities as it has for nerve and muscle.

B. Batteries Used.

I will not here refer to the rotary or magneto-faradic instrument, as it is antiquated and rarely used, although perhaps preferable under certain circumstances, for its effect upon diseased muscle and for its convenience upon the frontier or in distant posts, as an instrument much less liable to disturbance, and not dependent for action upon solutions which may evaporate or deteriorate or are entirely out of reach; so also in emergency cases it is serviceable, as always ready for action.

Diseased muscle reacts more readily to the magneto-faradic than it does to the galvano-faradic current, as the rise and fall of potential in the former is less rapid, and time is an important element for the muscle current. Therapeutic tests have proven this, and Gaiffe describes a case of lead poisoning in which the muscle did not react to the galvano-faradic current, but was forced to response by the magneto-faradic.

Healthy nerve and muscle react to from 0.28 to 0.56 micro-coulomb of a condenser discharge (Edelmann), and time is a factor in the effect of the discharge on diseased muscle, healthy muscle reacting to a condenser discharge of $\frac{1}{10000}$ second, whilst diseased muscle needs from $\frac{1}{1000}$ to $\frac{5}{1000}$ second, and the greater length of time of the magneto-faradic discharge induces its more potent effect on diseased muscle. The galvano-faradic are the medical instruments of the present day, and these, as universally used up to this time, are constructed on one and the same plan, varying only in shape and size and in the mechanism and

perfection of their component parts. For the proper utilization of the variable and valuable therapeutic properties of the faradic current an apparatus more perfect in its interrupter and coils is necessary, but I shall here confine myself to the instruments now in general use, as these are the ones with which the physician must deal, for the present at least, until the new apparatus is more generally understood and introduced.

The faradic battery, or medical induction apparatus, is an electromotor in which we utilize the effect exercised by change of force in electrized or magnetized bodies upon neighboring circuits, and in which the closing current preponderates over the opening current, upon which physiological power is concentrated so as to give this the utmost efficiency; this opening current, or current of break, is the essential feature of the direct or extra, and likewise of the induced secondary faradic current, as well as the gauge of strength and direction of both.

I need not describe all trifling differences of construction, prominent among which is the Kidder single or continuous-coil apparatus, consisting of a series of three or four conaxial coils, movable over each other, in which the terminals of the secondary coils are not free as in the ordinary instrument, but connected with the primary circuit from which the current is taken, so that the primary as well as the induction flow is utilized. Since the individuality of the primary coil, an idea advanced by Duchenne and long retained, is proven a myth, and the peculiar effect ascribed to it has been shown to be due mainly to the quality of the coil,—the short, coarse wire,—we no longer use the primary current. We can obtain the same effect from a similar secondary coil, the alternation of the secondary current and the induction effect in no way interfering; so that we now ignore the primary circuit, which does not truly give a pure interrupted galvanic current, as the induction effect preponderates, but we arrange the apparatus so as to concentrate its efficiency upon the secondary circuit, thus obtaining uniformity and a much wider range of variation, greater precision, and the possibility of comparison.

Such is even the modern instrument, with variation in shape and size in accordance with the purpose for which it is constructed, and greater or less delicacy and perfection of mechanism according to price; but at best it is incomplete, and ere long I hope to be able to present to the profession an instrument which will enable us to properly utilize the valuable qualities of faradic electricity.[1]

In the instruments as now in general use we have three distinct styles: (*a*) the pocket-battery; (*b*) the portable or box battery; (*c*) the stationary or sledge instrument. In all the vibrator is acted by the coil current or primary battery flow, whilst in my new apparatus the inter-

[1] I may add that this instrument has just been completed, and has been displayed by the maker at the World's Fair, receiving the highest award; and I can safely say that we may soon hope to see it in the hands of the profession.

rupter is propelled by a separate motive power, so as to interfere in no way with the current proper.

(*a*) The type of the *pocket-battery* is the small Gaiffe instrument (Fig. 8), a neat box no larger than an octavo book, with two small sulphate-of-mercury cells, *L*, and with fixed coils, *M*, the core serving as attractor for the spring interrupter, *P*, the current-force being varied by the sliding tube, *R*. Extra and induced current, or both united, can be utilized from the connections in *E* by brass sponge-holders, *N*, or the metal electrodes, *T*. The battery-salt is carried in the bottle, *K*. Similar small instruments are made in the United States.

(*b*) The instrument most generally used is the *box-battery*. This is of moderate size and so arranged that it is portable, and yet can be made so complete that it answers all purposes and is in general use as an office instrument. These box-batteries vary greatly in size and perfection of construction, and are all equally serviceable for purposes of irritation or stimulation; yet the great majority of instruments do not admit of any other variation of current than in strength, as they have only the spring

FIG. 8.—POCKET-BATTERY.

interrupter, which cannot be adjusted sufficiently to admit of a physiological variation of current, and they mostly have but one secondary coil, and that of no great length of wire, thus giving a sharp current. One of the most perfect of these instruments is the box-battery (Fig. 9) constructed in accordance with my earlier suggestions, and possessing controllable contact-breakers, which are well adapted for current-interruptions within moderate limits, and of greater variability than in other instruments. We see the three coils, one in use and two others stowed away in the receiver, and three contact-breakers; the rapidly-vibrating spring, adjustable by the screw-head, *D*; the slow interrupter, whose beats are varied by the screw, *C*, and the single impulse-key, *H*. The galvanic flow is established by inserting the zinc, *F*, into the adjoining bichromate-of-potash element, and making the battery connection by means of the metallic bridges, *E E*. The coils with which this battery is armed are those first advocated by me in 1886: Coil I, 577 winds, 0.8 ohm resistance; Coil II, 1750 winds, 13 ohms resistance; Coil III, 4000 winds, 250 ohms resistance. They accompany every instrument and suffice for ordinary needs, but for special or more delicate work others

must be added, as they are used with the new apparatus, and can be fitted to this. Innumerable very excellent box-batteries are made, but all on very much the same plan, with no possibility of current variation save by the sledge; though we must make an honorable exception of the Gaiffe and Flemming and the instruments of the Galvano-Faradic and Dry-Cell Battery Company, the latter of which have but quite recently appeared; in fact, our American instruments now far surpass those made in other countries.

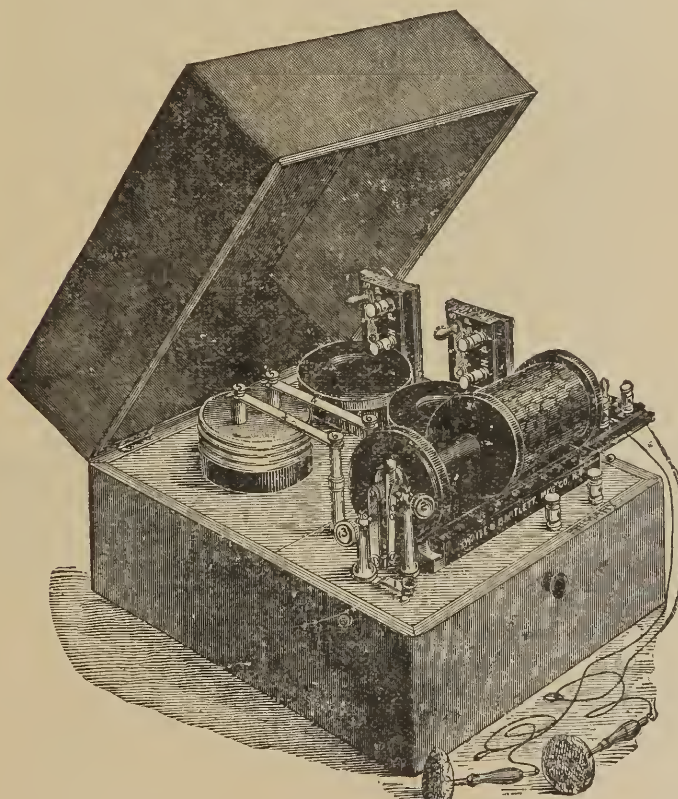


FIG. 9.—BOX OR PORTABLE BATTERY.

(c) *The Sledge Battery.*—The most perfect instruments, such as are furnished for cabinets and used by specialists, though on the same principle, are not boxed up, and are always made in the form of the Tripier or du Bois-Reymond sledge, a long slide or sledge admitting of an extended withdrawal of the secondary coil, thus yielding maximum effects and minimum currents for delicate physiological work. The utmost perfection of mechanism is found in this form of the faradic apparatus, for which the galvanic force is supplied by a Grenet

cell, or a battery of from 2 to 4 Leclanché elements. In most American instruments of this form the core is the magnet which serves the vibrator, whilst in those of foreign make the trembler is attracted by a small electro-magnet distinct from the core; though I know of but one, save my new apparatus, the Edelmann faradimeter, in which it is propelled by an independent force; yet such must be the case if any precision is to be obtained.

Fig. 10 is one of the best instruments of this kind, showing an ingenious contact-breaker, *I*, attracted by the small electro-magnet, *E*, which varies the interruptions from 1 to 50 per second by the change in the slant of the bar, *I*, in moving the foundation, *L*, from *L′* to *L″*, and by varying the position of the globular weight, *S*; *P* is the single impulse-key, and *i* the current-reverser.

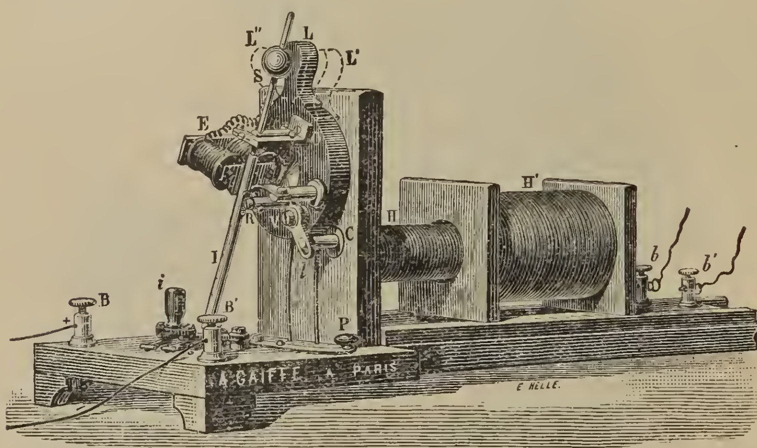


FIG. 10.—SLEDGE INSTRUMENT.

Fig. 11, varying only in detail from the box-battery, is the most complete of the old-style instruments made to supply a medical current as developed by the vibrator without the aid of the independent controllable contact-breaker. The cut represents the old instrument with the vibrator as propelled by the inducing current and attracted by the core, whilst the new apparatus, with the same vibrators and coils, is so arranged that the battery flow for each is independent of the other, and both vibrator and coil current is supplied with a rheostat so that every possible modification of force can be obtained, and the rapidity of vibration need in no way be influenced by the variations in the inducing flow, as is the case in all other instruments in which a change in the position of the coils or the force of the inducing flow at once alters the rate of vibration. This apparatus shows the same arrangements for contact-breaking as Fig. 9, but is supplied with some additional details, such as a fine movement, *J*, for the gradual sliding and pre-

cise adjustment of the coil on the sledge or scale. The long coil of fine wire is supplied with a lever, *K*, by means of which different lengths of wire can be utilized; thus, in one coil of 6000 feet the wire is so switched off that it may serve as a coil of 3000, of 4500, or of 6000 feet. Any number of the four elements supplying the primary force can be employed, by means of the lever *A*, from 1 to 4, as may be demanded by the nature of the circuits employed, the resistance of the battery and body circuits, or the effect to be obtained.

An instrument varying in several important elements from any previously constructed is my new apparatus (Fig. 12), which furnishes all the different qualities of faradic current with the greatest possible range of variation and under the most perfect control; so that I may say that it is an instrument which will establish faradism on a firm basis as a therapeutic agent, since it admits of a perfect control of the current and of a precising so necessary to dosage; but it will also greatly extend the range of its applicability, since increased range of coils and rates of vibration give currents of therapeutic power hitherto unknown.

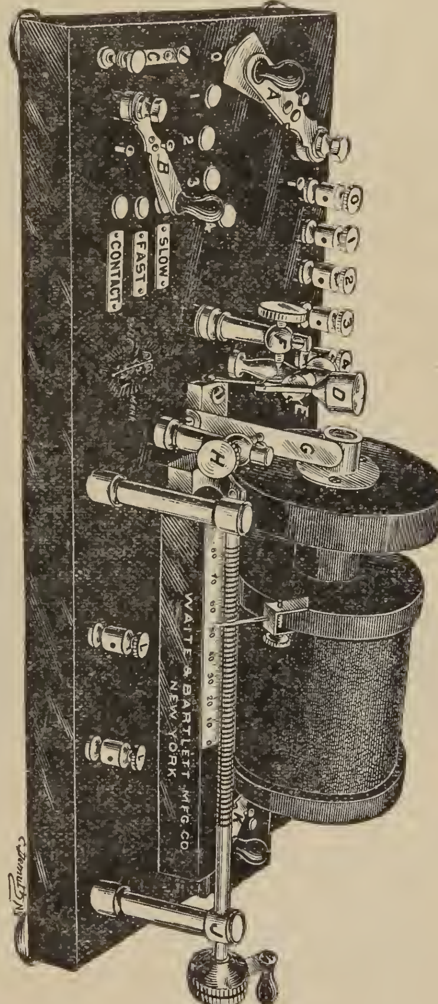


FIG. 11.—SLEDGE INSTRUMENT (ENGELMANN BATTERY).

1 to 4, binding-posts to connect cells; *A*, lever to introduce 1, 2, 3, or 4 cells; *B*, lever to introduce for varying interruption, to use slow, fast, or single impulse; *C*, single impulse-key; *D*, slow vibrator; *E*, controller for slow vibrator; *F*, regulator for slow vibrator; *G*, fine or fast vibrator; *H*, regulator for fast vibrator; *J*, fine movement for coil; *K*, lever for insertion of different lengths of coil; *L*, *L*, binding-posts for rheophores.

This instrument differs from all others, in the main, in the following points: (1) the separation of the vibrator or interrupter current from the therapeutic or inducing flow; (2) in the variability, controllability, and rapidity of the interrupter; (3) in the range and precise definition of the secondary coils; (4) in the possibility of interrupting or alter-

nating primary or secondary current at will. The cut represents the apparatus but partially.

The inducing current here used is entirely independent of the current which produces the interruptions, be it by means of the new contact-breaker here represented or by the series of vibrators which is also attached to the apparatus as made for me; this inducing current can be varied (*a*) by the use of any number of elements as introduced by moving the switch to points 1, 2, 3, or 4; (*b*) by the sliding of the coil on the graded sledge; (*c*) by the rheostat directly in front of the coil. The second rheostat, by the side of the first, is for the purpose of regulating the vibrator current, for single-impulse key, slow and fast vibrator, as in Fig. 11, but not represented here.

1. *Coils.*—To the right is the coil, with sliding scale and fine movement. The coils used in connection with the apparatus are devised for

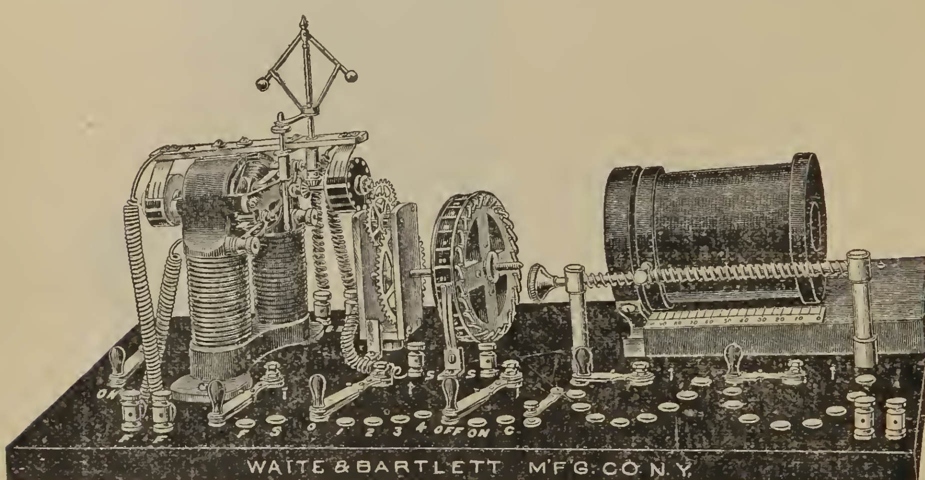


FIG. 12.[1]—NEW ENGELMANN BATTERY WITH VARIABLE AND CONTROLLABLE INTERRUPTER AND ALTERNATOR.

certain therapeutic purposes; their quality and quantity is designated by electro-motor force (number of winds) and resistance in ohms.

For motor, to the exclusion of sensory effect,—that is, the painless influencing of the muscle,—secondary coils of the lowest possible resistance are used, *i.e.*, coils with a comparatively great electro-motor force:—

[1] At the very last moment, while reviewing the proof of this paper, I was fortunate enough to receive this cut (Fig. 12) of my new faradic apparatus, to the perfecting of which my leisure moments during the past year have been devoted, and it is by reason of the tardy completion of this new apparatus, new in principle and in construction, that I can here give but a brief description of its salient features. I must add that the admirable carrying out of my ideas and the perfection of mechanical details are entirely due to Mr. Harry F. Waite, of the firm of Waite & Bartlett, New York.

Coil I: 528 winds, 0.8 ohm resistance.
Coil II: 6500 winds, 4.1 ohms resistance, No. 32 wire in multiple.

The opposite condition—revulsion, nerve irritation, without affecting the muscle—is produced by a coil of high resistance and low electro-motor force:—

Coil III: 528 winds, 180 ohms resistance.

The utmost penetration, together with general therapeutic effects, is obtained by coils of greater electro-motor force and higher resistance:—

Coil V: tapped at three points, 4000, 6000, and 8000 winds, from 250 to 750 ohms resistance.

Coil VI, producing the utmost sedative and even anæsthetic effect, is a coil tapped at 5600, 9600, and 13,000 winds, with a resistance of 2500 ohms to its highest electro-motor force.

Coil IV (II of the old set) gives rather a sharp, yet penetrating current, 1750 winds, 13 ohms resistance.

To better illustrate these figures I will say that the most efficient of the coils in general use have been those of 3500 to 4000 winds, or 2000 feet. Each of the coils I have in this apparatus answers a definite purpose, attaining the desired result best without complication by other unnecessary and often deleterious effects.

2. *Contact-breaker.*—To the left is the contact-breaker or alternator and interrupter, a small motor propelled by an accumulator or by a Grenet cell, on its shaft an interrupter to one side and an alternator to the other. This contact-breaker serves to interrupt the current from 2500 to 50,000 times a minute: slower interruptions are produced by the large wheel in the centre of the figure, which also serves to determine the rapidity of interruption.

The advantages of this interrupter are (1) that it is propelled by an independent force, and may be used as interrupter or alternator for secondary or primary current or for the galvanic; (2) that the rate of interruption is perfectly controllable and regular, in no way influenced by the intensity of the therapeutic or inducing current.

The perfect controllability of this instrument, by speed indicator, rheostat, and am-meter, enables us to record and dose the faradic current, and its rapidity enables us to secure sedative and anæsthetic effects which can be obtained in no other way.

The absolute precision of record is perhaps the most important feature, as this is something which has been repeatedly attempted but never hitherto obtained, any comparison with the tuning-fork being at best but vague and only possible now and then for an experiment, but of no practical value for the office or for clinical work, and, moreover, a regulation of vibrators within the wider range necessary for therapeutic purposes is impossible, at least for actual work. Higher rates of interruption can easily be obtained, but my experiments have shown that this is practically useless for induction apparatus as now constructed; and

until electro-motor force and resistance of primary and secondary coils, as well as the quantity of the primary flow, is greatly changed, we cannot utilize interrupters more rapid than this, giving 50,000 interruptions per minute.

C. Electrodes.

Electrodes, or instruments for the therapeutic application of the induced current, are many and varied in shape and material, according

Fig. 13.—Sponge-Covered Disc.

to the part to which they are to be applied and the purpose for which they are to be used; yet the paucity and simplicity of the electrodes which accompany the average faradic apparatus, the old-time brass or vulcanite sponge-cup, or the now universal sponge-covered disc, has done much to limit the use of faradism, these being given into the hands of the physician as *the* instruments for its application, yet serviceable only for a very limited range of therapeutic use.

Strange as it may seem, the electrodes, or instruments devised for the therapeutic application of faradic electricity, are more numerous and

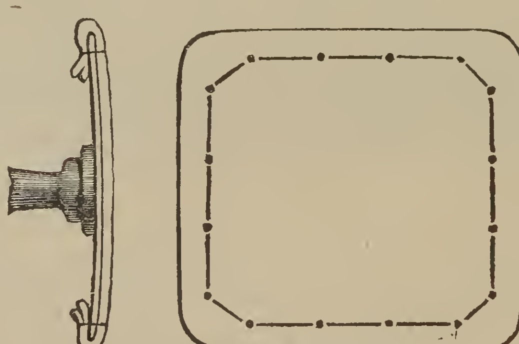


Fig. 14.—Plate Electrode.

diversified than those for the galvanic current, as its uses are more varied and it is more liable to be applied to deep-seated organs and to the cavities necessitating instruments of peculiar construction for each separate part; numerous electrodes are made for localized and bipolar faradization, for faradic massage and the faradic bath, and I will briefly describe the more important, as they are by no means so well known as galvanic electrodes.

I. ELECTRODES FOR GENERAL AND LOCALIZED FARADIZATION.

In polar treatment we use the dry metallic electrode for superficial, revulsive, or skin effects, and the moist electrode for muscles, nerves, and deep-seated tissues, for the penetrating current. Metallic electrodes are the circular or rectangular discs and plates of the instruments in Figs. 13 and 14, small globes and cones, and the faradic brush,—a bunch of fine wires trimmed so as to present a smooth, even surface. Instruments of suitable shape are made for the application of this current to the vocal cords, the uterus (Figs. 15 and 16), and the bladder.

In scientific experiments it must be remembered that the polarization of these electrodes affects the current more or less, and that for purposes of precision non-polarizable electrodes must be used, or at least

FIG. 15.—CUP-SHAPED ELECTRODE FOR OS UTERI.

the extent of this action must be studied and accounted for. Every particle of oxide on the surface of the electrode offers a resistanee to the current, and thus weakens its effect; so that much current-strength is lost in old, badly-kept instruments. More generally used are the moist electrodes, made by covering the conductor with an adaptable moisture-retaining substance, for penetrating, nerve and muscle currents.

The sponge was, until of late, universally employed,—an uncleanly appliance, as it was used again and again, for patient after patient; not alone dirty, it was imperfect, as its coarse meshes did not admit of close adaptation to the part to which it was to be applied; and as resistance and density of current are in direct relation to the surface of the electrode, this is an important factor; unless perfect coaptation and contact at every point exist, the size of the electrode is by no means equivalent

FIG. 16.—BEARD AND ROCKWELL'S INTRA-UTERINE ELECTRODE.

to its active surface, that surface being constituted by the points in close contact with the tissues. Moreover, the penetrating power of the electric fluid is dependent upon the resistance offered; and as, for induction currents especially, the surface or skin resistance is great, the perfect coaptation of the electrode is of importance, as it serves to overcome this, lessens the pain, and adds to the efficiency of the current by causing a diminution of the resistance of contact or passage (Uebergangs Widerständc). Cloth and the ordinary chamois, even when wet, has a rough surface and does not admit of perfect contact as an electrode covering; nor does it hold enough moisture, upon the superabundance of which we must rely for perfect contact, as no material can adapt itself to every little

irregularity of the skin as water does. The saturating fluid serves to make more points of contact, and, by moistening the dry epidermis, to reduce its resistance,—an effect which is increased by increasing the conducting powers of the fluid by warmth and the addition of a small percentage of salt.

We need, for penetrating, painless currents, electrodes with the greatest possible number of points of contact for their surface, as the

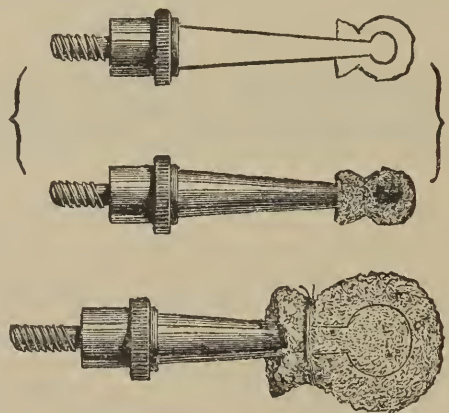


Fig. 17.—Ball Electrode.

density in each is diminished by an increase in their number; hence the metallic conductor of the electrode must be covered by a pliable and adaptable material which will absorb and hold an abundance of fluid. The cleanest and most simple is absorbent cotton, which is renewed for each application: this can be used on all smaller electrodes, being renewed for each application. Punk, which I use to cover larger plates, is of finer texture and an equally good absorbent, and can be used to advantage on the smaller instruments, a supply being kept on hand

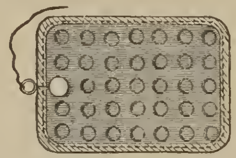


Fig. 18.—Engelmann's Punk Electrode.

for renewal. Metal or carbon plate, ball or cone (Figs. 13, 14, and 17) are surrounded by a thick layer of the cotton, which clings when moistened and needs no fastening to hold it in place; a rubber band will serve to hold the punk. For the larger plate electrodes (Fig. 14) this can also be used, and if it is to be permanent it may be held in place by a fine, thin chamois; one or two layers of well-selected punk, in place of the cotton, underneath the chamois, are most satisfactory and make an admirable

conductor. The basis is a thin sheet of pliable tin, lead, or amalgam, perforated in a number of places to give free access to the fluid.

This is the same electrode (Fig. 18) as the one I recommend for the indifferent pole in galvanization, and made in the same sizes, the smaller

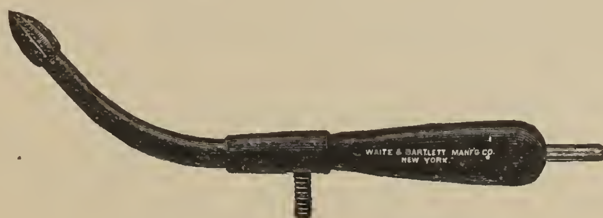


FIG. 19.—KING'S RECTAL ELECTRODE.

numbers being more generally serviceable for faradization; being flat and pliable, it is extremely convenient for abdominal application, as it can be slipped under the dress without disturbing the patient, a warm towel

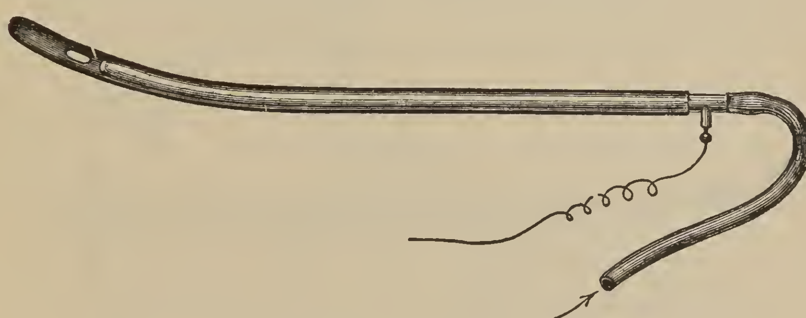


FIG. 20.—BOUDET'S RECTAL ELECTRODE.

or a piece of rubber tissue serving to protect the garment from contact with the moist plate. For labile applications the Erb electrode (Fig. 14) with handle must be used, but covered in the same manner, the smaller

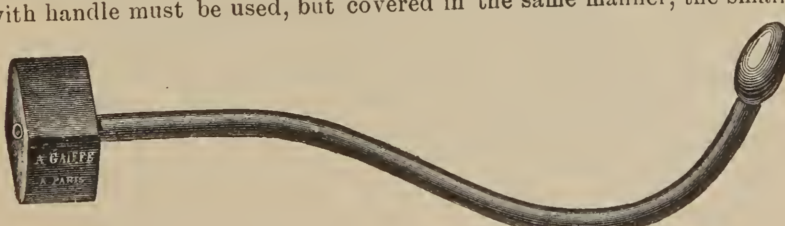


FIG. 21.—TRIPIER'S RECTAL ELECTRODE.

sizes always with absorbent cotton or punk, and these, especially when long and narrow, one-half by two inches, two by four, two and one-half by five, though not so generally made, are very useful in local faradization.

Character and size of the electrode are prominent factors in deter-

mining therapeutic effect, as upon this depend density and resistance, the character and effect of the current, and these points must always be noted for purposes of record and comparison. In body-cavities a quantity of fluid to which the current is carried by the electrode may serve as distributor; thus, in the rectal electrode of King (Fig. 19) or that of Boudet (Fig. 20) warm salt water is used as the active pole within the bowel in the treatment of constipation. This is a great improvement over the old-time instrument with metallic end, which so long stood in the way of this valuable method of treatment, which, if ever attempted, was soon discontinued on account of the sharp, painful current from the metallic electrode. which, moreover, was far less penetrating, less diffuse

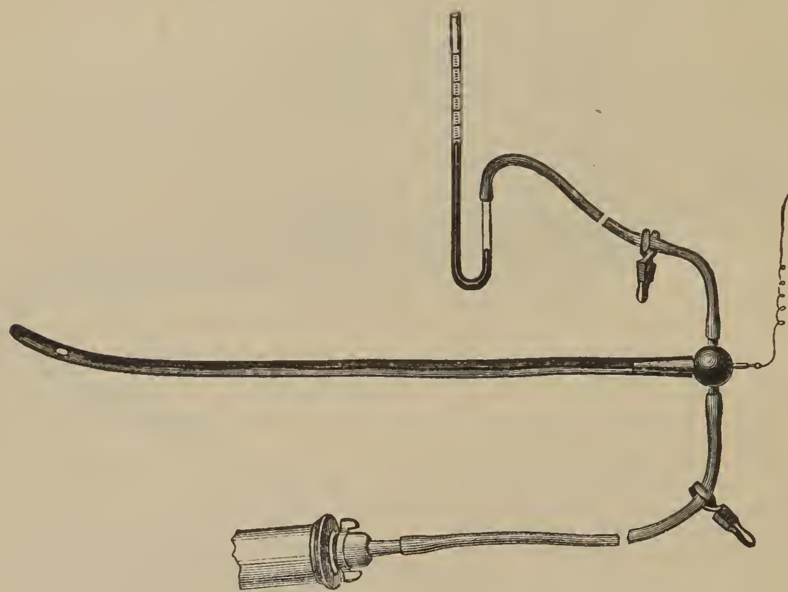


FIG. 22.—VESICAL ELECTRODE OF BOUDET, WITH MANOMETER.

and effective as a muscular stimulant and contractor. In this instrument, as in that of Boudet or the new electrode of Waite & Bartlett, no metal can possibly come in contact with the tissues; in the former the vulcanite bulb, in the latter the rubber catheter, through which the fluid is injected, guards the tissues against the inclosed metallic conductor.

A similar instrument is the vesical electrode of Boudet (Fig. 22), to which a manometer is attached for the purpose of recording the various phases of the disease, by measuring the contraction of the vesical muscle produced by the current in the course of the treatment.

(*b*) *Bipolar electrodes* are those in which both currents are applied by means of one and the same instrument, which carries the two poles, and are mostly used upon the mucous membranes, within body-cavities, in

uterus, vagina, bladder, and rectum. Thus the rectal electrode of Tripier (Fig. 23) and a similar instrument by Bergognié (Fig. 24), supplied with a manometer for the study of the contractile powers of the sphincter muscles. The rubber bulb, *B*, is compressed by the contraction of the muscle as it responds to the electric current, and the extent of this reaction is indicated by the manometer connected with the bulb by a rubber

FIG. 23.—TRIPIER'S RECTAL ELECTRODE.

tube, *C*. The instrument is a valuable one for the determination of the cause of constipation, the determination of the extent of muscular weakness, and the observation of its improvement under this admirable, but little-used, method of treatment. Whilst this instrument is admirably adapted for purposes of observation and measurement, it is, like all metallic electrodes within the bowel, unfit for continued treatment.

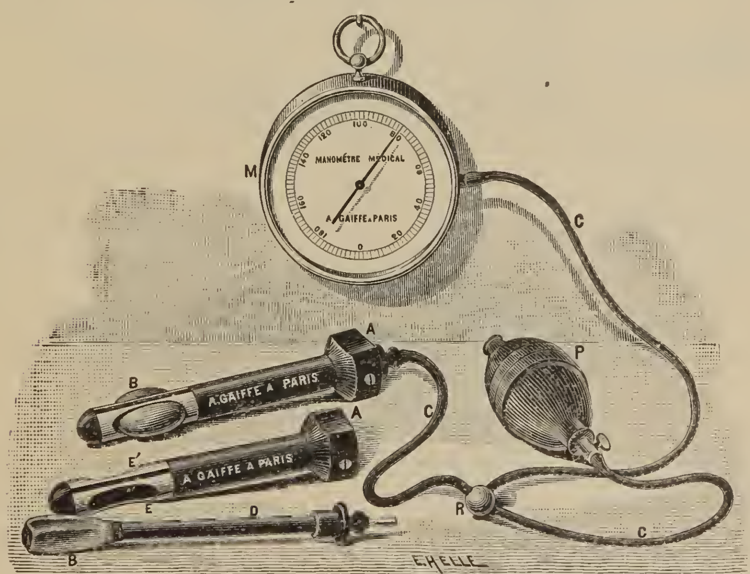


FIG. 24.—BIPOLAR RECTAL ELECTRODE OF DR. BERGOGNIÉ, WITH MANOMETER.

Only the cotton-covered instrument, or, better still, the catheter apparatus, with water as the conducting agent, should be used, and, further, it is rarely the case that only one point is affected, demanding the localized application by a bipolar eleetrode; the polar method, with one abdominal electrode, is decidedly preferable. Bipolar intra-uterine applica-

tions are far more frequent and numerous: instruments are made for this purpose, but these are mostly useless or dangerous in all but large cavities, as they are not pliable, and of necessity not sufficiently slender, car-

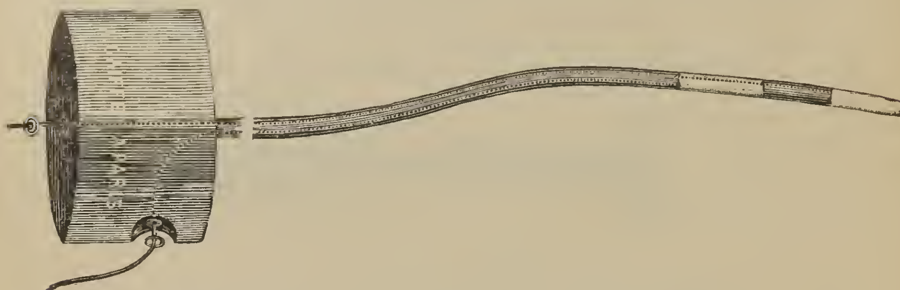


FIG. 25.—BIPOLAR INTRA-UTERINE ELECTRODE OF APOSTOLI.

rying two insulated conductors; so that they cannot be inserted in a narrow or curved canal unless some force is used. Fig. 25 is the bipolar intra-uterine electrode of Apostoli, and Fig. 26 that of Gunning. Va-

FIG. 26.—GUNNING'S FLEXIBLE DOUBLE-CURRENT INTRA-UTERINE ELECTRODE.

ginal electrodes of various kinds are made; that of Tripier consists of the insulated blades of a speculum, but mostly the two poles are upon a rubber bar, as metallic circlets (Fig. 27), one to two inches apart, or

FIG. 27.—BIPOLAR VAGINAL ELECTRODE OF APOSTOLI.

longitudinal strips parallel to each other: the surface of the metal is generally even with that of the non-conducting stem and does not come thoroughly in contact with the tissues; this difficulty is obviated in the

FIG. 28.—BIPOLAR VAGINAL ELECTRODE.

admirable instrument (Fig. 28) recently furnished by Waite & Bartlett, in which the metallic poles are rounded, protrude over the stem, and are so arranged that they can be approximated to or removed from each other.

Quite a variety of electrodes are constructed for diagnostic purposes, especially for the testing of cutaneous sensibility: these are pointed, conical instruments, and carefully-made wire brushes; but as the points of the wires in these brushes cannot all be made perfectly even, bundles of wires imbedded in a vulcanite mass are used; the ends, cut square and polished, present a smooth, metallic surface, in which each terminal is in the same contact, and it is sufficiently large (two centimetres in diameter), with a sufficient number of points to overcome any source of error from perspiration, irregularities of the skin, small nerves or glands.

II. MASSAGE ELECTRODES.

For the application of *faradic massage* we use rollers or plates made of a conducting material, and supplied with a handle, so that the

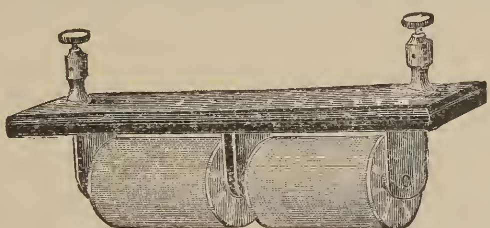


FIG. 29.—PIFFARD'S ROLLING RHEOPHORE.

current is carried by the same instrument which exercises the pressure upon the tissues. The electrode of Mordhurst is a plate, varying in size according to the part of the body to be treated, with a medium of one hundred and twenty square centimetres; of the rollers, the rheo-

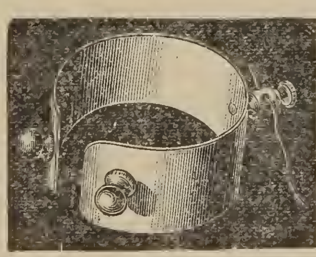


FIG. 30.—WRISTLET ELECTRODE.

phore of Piffard (Fig. 29) is a type; another instrument is the wristlet electrode (Fig. 30) for rubbing, massage, and digital diagnosis.

III. BATH ELECTRODES.

The electrodes in use in the *faradic bath* are generally large plates, preserved from contact with the body by non-conducting, protruding frames (sometimes an air-cushion is used), the metal plate being some ten by twelve inches for the back or neck, and nine by eleven at the

foot end. Smaller electrodes are made for the purpose of localizing the current in the bath to some one part of the body; but for a general distribution of the bath-current the large plates generally used are entirely unnecessary, as a few inches of the terminal of the battery-wire flattened out or coiled answers precisely the same purpose, and must, of course, be likewise preserved from contact with the body.

Local baths or douches are applied by means of metallic spouts, with a non-conducting handle; these spouts, like those of a shower-bath or watering-pot, are perforated; the water is forced in delicate jets through the numerous small openings, the spray being the rheophore by which the current is applied to the part. For back and chest the spouts are rectangular, or round, some two inches in diameter; a long, narrow one is made for the spine, three-fourths to one inch by two or two and one-half inches; a plate-electrode is, of course, necessary for the indifferent pole.

IV. CHOICE OF BATTERY AND ELECTRODES.

The proper selection of apparatus, of battery and electrodes, is all important to the physician who would use faradism to advantage in his practice, and afford his patient all the benefits of this variable and effective form of electricity. Notwithstanding the off-hand statement made in so august a body as the International Congress of Electricians, only one year ago, that "der kleine Spanner," the average small German box-battery, was sufficient for all purposes, the *choice of an instrument* is of *great* importance, and, although a recent text-book tells us that it is "of small importance," as "the details of construction can safely be left to the maker," and certainly far less important than the choice of a galvanic apparatus, this is by no means the case. The choice of the faradic apparatus is all-important, as upon its *mechanism and construction* depend the *character* and *efficiency* of the current, whilst this is not the case in the galvanic battery. The galvanic current is the same whether taken from a home-made instrument of two dozen fruit-jars into which the carbons and zincs are placed, if they are but properly coupled, or if it is from a battery in mahogany box or cabinet; but the character of the faradic current varies more or less with every detail of construction, with length, thickness, and kind of core, dimensions of coils, length and thickness of wire, insulation, number and character of interruptions; and its utility depends greatly upon the method of contact-breaking and of gradation of current.

The physician who desires not only an irritating, stimulating current, but wishes to obtain the utmost efficiency and variability of faradic electricity, must consider various points. Granting precision and perfection of construction, as we may expect this in instruments from any reliable maker, the essentials to be looked for are as follow:—

1. The possibility of varying the number of interruptions *at will*,

from one up to *at least fifty thousand per minute* (50 per second—3000 per minute—is the limit for the majority of instruments now used).

2. The separation of the inducing flow, or the coil current, from the battery power which acts the trembler; in other words, a separate motive power must be used for coil and contact-breaker in instruments of precision from which an even and thoroughly controllable current is to be expected.

3. The gradation of current-strength by the sliding of the secondary coil over the primary upon a scale-sledge, which for a perfect instrument should indicate in micro-coulombs the current-value for each coil, for a given current, and for a given medium body-resistance, although until a more perfect method of measurement is discovered the simple division of the scale may answer. The mobility of the core is necessary, and, of course, on a scaled slide; but this is not for the varying of current-strength, but of current-quality.

4. The instrument must have a series of, at the very least, three secondary coils for muscle, nerve, and general effects; one with low resistance and as high an electro-motor force as possible, usually a short coil of heavy wire; another long, of not less than 5000 to 9000 winds, of very fine wire, with one intermediary.

This is the very least that can be asked; more must be demanded of an instrument from which the utmost efficiency and variability of current is expected. The series of coils must have a greater range, and each must be adapted to the special purposes for which it is constructed: for muscular stimulation, for counter-irritation, for sedation, and for general nerve and muscular effects. A fine-wire, multiple muscle-coil is desirable, a short fine-wire coil for counter-irritation, and also a sedative coil with from 1000 to 13,000 winds. Above all, the contact-breaker must be independent of the inducing current and be so arranged as to break the contact any given number of times up to twenty or fifty thousand per minute. As for the electrodes, I can only say that absorbent cotton or punk should always take the place of the old-time sponge; and perfect coaptation should be aimed at, whatever the nature of the application, unless revulsive. For penetrating currents the material in direct contact with the skin must be of fine texture, a perfect fluid-absorber, and in sufficient quantity to retain it in abundance: the carbon discs now in vogue are not as satisfactory as the metal, since they must be covered in the same manner to secure penetrating currents; the chamois or flannel covering with which they are sent out, as an accompaniment to the battery, makes an imperfect appliance, which but partially answers the purpose for which it is intended, the resistance being great and the adaptable surface comparatively small.

As electrodes must be selected with reference to the uses to which the current is to be applied, and the range of application is so extensive, the merits of individual instruments cannot here be discussed.

A great variety of efficient electrodes is to be had, each serving its especial purpose, and the practitioner will soon discover the long-ignored merits of the interrupted current if he will but study the nature of this pliable form of electricity and avail himself of its variable powers by using currents from properly-constructed apparatus, and apply them by rheophores adapted to the object in view. Let the demand be created, and numerous serviceable instruments will soon be placed within reach of all.

GALVANISM.

By J. MOUNT BLEYER, M.D.,

NEW YORK.

In preparing this *résumé* of research and investigation, so far-reaching and comprehensive, I naturally cannot fail to accord due credit to the tireless workers to whom our profession is indebted for its knowledge of electrical energy as we now understand it. Particularly let me thank those gentlemen whose works I have made use of, and to whom credit is given in the "Bibliography."

In touching upon the critical value of batteries and precision instruments employed by medical men, I shall leave what comment there is to be made to my co-editors and colleagues who have prepared the other chapters of this work, and upon whose ground I do not mean to tread. While engaged in my labors I kept in mind that all-important consideration, that most busy medical men will hail with delight and read with interest what little I have to say upon the elementary physics of electricity. This, it seemed to me, was all important for a clear understanding of the practical application and usefulness of electricity to the practitioner. The mathematical consideration of the science I have only superficially touched upon, but refer you to the many exhaustive treatises on electrical measurements for additional light.

Historical Sketch of the Rise of Electricity.

To wield the thunder-bolt was the marked attribute of the chief gods of old; the lightning-flash was the surest proof of the presence of the divinity. Indra, the Jupiter of the Hindoos, was the god of thunder; the Etruscan Tinia always guided the electric storm; Jupiter Tonans waved his thunder-bolt over trembling Rome; and in every form of ancient superstition a belief in the divine origin of the most startling of the heavenly appearances lay at the base of the national faith. When it thundered the grave Romans dissolved their political meetings and the wise Greeks listened with unfeigned awe. The gods spoke from the heavens in the rattle of the passing storm, or wrote their rage upon the earth in the ruin of the lightning-stroke. And now, like Indra, Tinia, or Jupiter, the genius of modern civilization bears in its right arm the thunder-bolt as its crowning attribute. It has snatched the lightning from the skies and made it the most docile of servants. The electric flash is busy day and night in doing the work marked out for it by our modern magicians. It flies swifter than Ariel to carry its master's message, and puts a girdle round the earth. It dives in mid-ocean, rides over desert and forest. It prints our books, prepares our

paper; it dissolves our gems and consumes platinum. An electric light turns night into day; electric processes aid almost every kind of mechanical labor; and the thunder-bolt of Jupiter is everywhere toiling in the cause of human progress.

Of all the achievements of modern civilization this is the most

FIG. 1.—BENJAMIN FRANKLIN.

remarkable. Steam is gross and material; there is little that is poetic or great in the rattle of the train or the roar of a monstrous engine. We can easily account for the mightiest of machines impelled by boiling water. Gunpowder and nitro-glycerin, oxygen and hydrogen seem the natural servants of inventive man. But when we attempt to catch the idea of the electric spark, it still appears almost as superhuman and ter-

rible as when it flashed fear into the hearts of Greeks and Romans. It obeys with scrupulous accuracy; it performs the smallest, as well as the most important, tasks with equal care; it is as docile as was the genie to Solomon's seal; and yet it still remains shadowy, mysterious, and impalpable. It still lives in the skies, and seems to connect the material and the spiritual. Whence come these tongues of fire; these sharp shocks; these pale, ghostly lights that play around us and mock the master they obey? Who is it that wields this electric element, which seems to be the very base and source of our existence?

Some such sentiment of mysterious awe pressed upon the mind of Thales, the Franklin of Miletus, when, twenty-five centuries ago, he probably discovered electricity.[1] A sage of Greece, the philosopher's keen eye watched the minute phenomena of nature. His mind was eager for every kind of knowledge. He studied morals, metaphysics, life; and upon a narrow field of facts he erected vast fabrics of speculation, which were designed to embrace the whole origin and destiny of man. Phœnician voyagers, who were in the habit, in that dim age, of sailing out of the Straits of Hercules, and, perhaps, of coasting along the desolate shores of Europe until they reached the Baltic, brought back from the savage seas of Prussia a substance greatly prized by the ancients for its fair color and delicate transparency. It was amber, or electron.[2] The natives found it floating upon the waves, or, perhaps, gathered it from the mines which still form a source of the wealth of Prussia, and the amber imported from the distant north was an important article of commerce with the southern natives. But to Thales it possessed a mysterious value. He discovered that electron, when rubbed, had the property of attracting to itself various light articles, as if endowed with volition. His discovery was the first step in the great science of electricity. But the philosopher did no more than record his observation and attempt to account for it, as he had already done with the magnet, by ascribing to amber a soul. He supposed that some hidden principle of life lay in the yellow jewel from the northern seas.

The discovery was never forgotten, and the peculiar property of amber was noticed and commented upon by various ancient philosophers. Theophrastus, three centuries later than Thales, observed the attractive power of electron, and perhaps lectured his two thousand disciples upon the animated gem. Pliny, the elder, also described the phenomenon, and believed, apparently, that the amber was rubbed into life by the action of his fingers. But the germ of the great science lay hidden in mystery. No ancient philosopher could for a moment have supposed that there was any connection between the animated electron and the wild electricity of the thunder-storm; that the same power was active

[1] Becquerel, Traité de l'Électricité; Pliny, N. H., i, pp. 37, 329.

[2] Ges Carthager, Bötticher, p. 75, thinks the Phœnicians reached Prussia. See Pliny, H. N., iv, p. 27; xxxvii, pp. 11, 12.

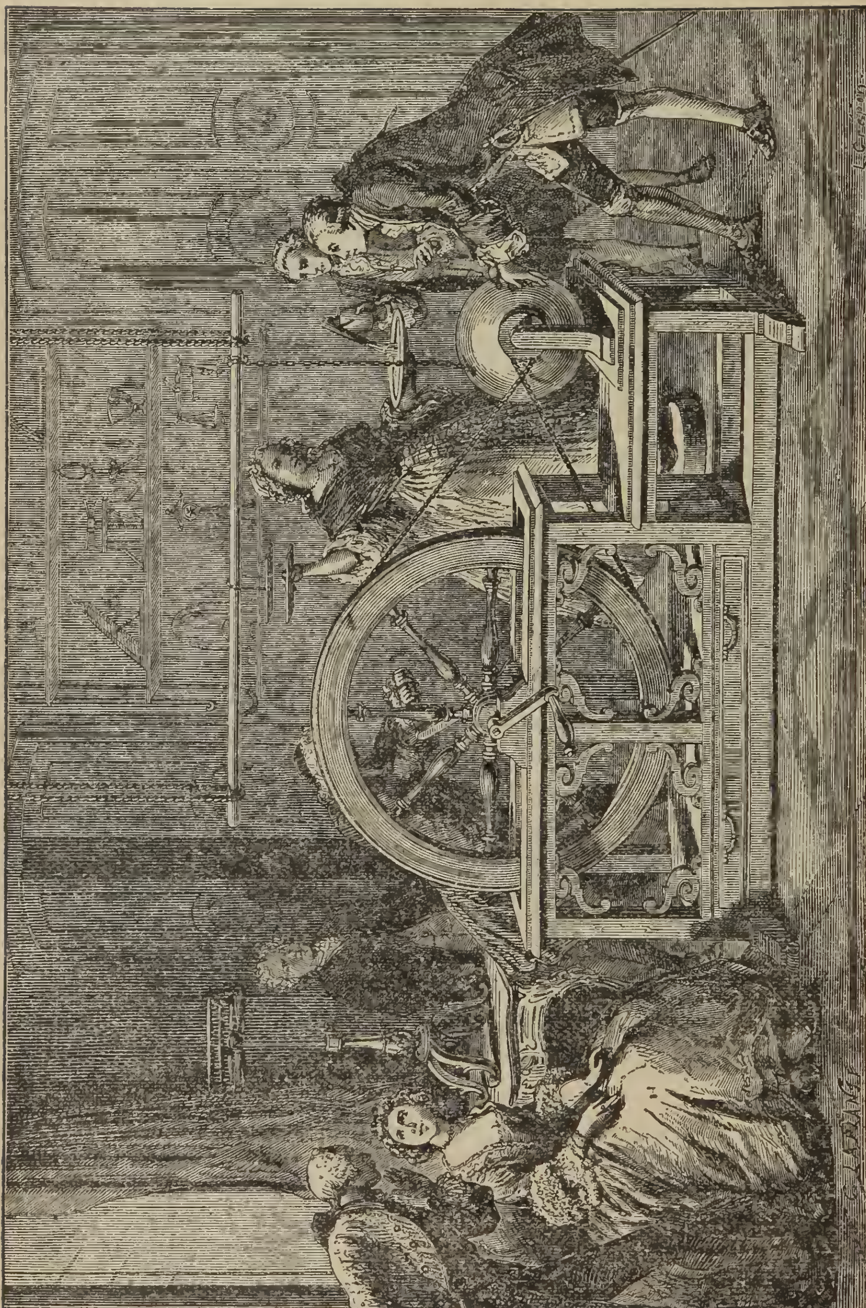


FIG. 2.—HAWKESBEE'S ELECTRICAL MACHINE.

in both, and that the secret of the amber was that of the thunder-bolt of Jove; that the precious electron was to create and to give a name to the most wonderful of modern discoveries.

Yet electricity, in all its varied phenomena, never suffered the puzzled ancients to rest.[1] It flashed along the spears of their long array of soldiers and tipped every helmet with a plume of flame. It filled even the immovable Cæsar with a strange alarm. It leaped down from the clouds and splintered the temples and statues of Rome, and did not spare the effigy of the Thunderer himself. It was seen playing around the ramparts of fortified towns, crowning their sentinels with a strange effulgence. Often the Roman or Greek sailors, far from land on the stormy Mediterranean, saw pale, spectral lights dancing along the ropes of their vessels or clinging in fitful outlines to the masts, and called them Cæsar and Pollux. But the science of electricity was still unborn. Meantime in ancient Etruria, the parent-land of Italian superstition, countless students were being instructed in the art of reading the will of the gods by the lightning.[2] The heavens were divided into various compartments. If the lightning-flash appeared in one, it was a favorable omen; if in another, it was fatal. The accomplished augurs, instructed by long years of study and toil, stood upon lofty towers, watching for the sudden gleam or a sudden peal of thunder, and knew at once by their divine art what undertakings would be successful, and when their warriors clad in brass should go forth to battle against Rome. The religion of ancient Etruria was almost a worship of electricity, and the land of Galvani and Volta was famous in the dawn of its history for the close study of electricital phenomena.

But no Tuscan augur or Roman priest made any progress in creating the science. Centuries passed away. Europe was torn by civil convulsions: men sank into barbarism and rose again into new activity; but the famous observation of Thales was never lost; and at length, in the opening of the seventeenth century, an Englishman named Gilbert began to study the properties of the electron. He was rewarded by a series of discoveries that, in the dawn of science, made his name famous over Europe.[3] Yet they were so meagre as to advance little beyond the early observations of Pliny. He enumerated various substances capable of producing electrical action; he noticed the influence of the weather on the electron and the magnet; and from his labors sprang up a science known as electricity. Gilbert's work, "De Magnete," was published in 1600, and soon the new science began to terrify and astonish men. Every fact as it was unfolded seemed spiritual and supernatural. Flames of fire played around the electrical substances in the dark; sparks glittered; sharp sensations, produced by the unknown

[1] Becquerel, i, p. 32. Plutarch, "Lysander," notices the luminous wonders.
[2] Müller, Etrusker, iii, pp. 1, 2. Arnob, vii, p. 26. Genetrix et mater superstitionis Etruria.
[3] Becquerel, i, p. 35.

agent, were felt by astonished operators; and a mysterious awe surrounded the birth of the wonderful principle. Men were almost inclined, like Thales, to invest the electrical substance with a soul.

An Englishman discovered electricity; a Prussian, in the land of amber, invented the first electrical machine. Otto Guericke, of Magdenburg, who also invented the air-pump, formed the instrument by which electricity could be most readily produced; he placed a globe of sulphur on an axle, to be turned by the hand of the operator, while with

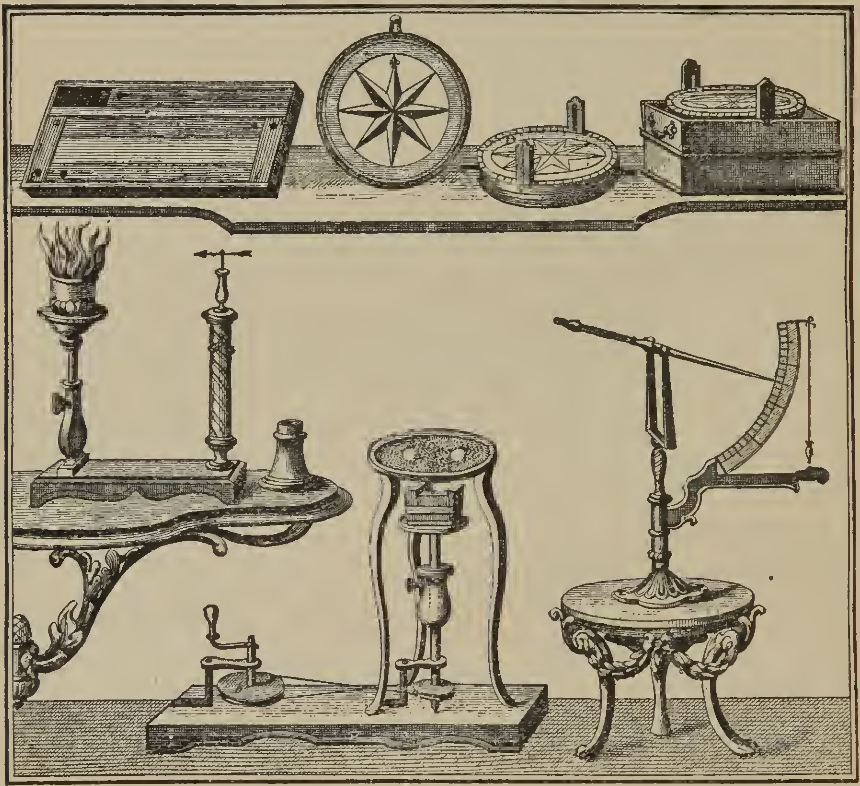


FIG. 3.—ELECTRICITY 150 YEARS AGO.

the other he applied a cloth to the sulphur to produce the necessary friction. It was a rude, imperfect machine, but it was at once found to have made a great revelation in the science. Electricity, which had heretofore been known only in its feebler forms, was now given out in sharp sparks, and displayed a thousand curious properties. Sometimes it attracted objects, at others repelled them. It seemed at times to exercise a kind of volition. The weather affected it sensibly; dampness dissolved its strength; it was capable, too, of influencing bodies at a considerable distance, and was apparently independent of the usual laws of

space. Yet the seventeenth century glided away, with its fierce religious wars and its wonderful voyages and settlements, while little progress was made in the knowledge of electricity. Newton paid no particular attention to the new science. He suggested, however, that the electrical substance was a subtle ether, filling nature, which could be set in motion by friction. Yet his bold, inquisitive mind was never attracted by the mysterious study; the flashes and sparks of the electrical machines seemed, perhaps, a puerile entertainment to the great student of nature's laws. Nor did any other eminent philosopher of the age suspect that

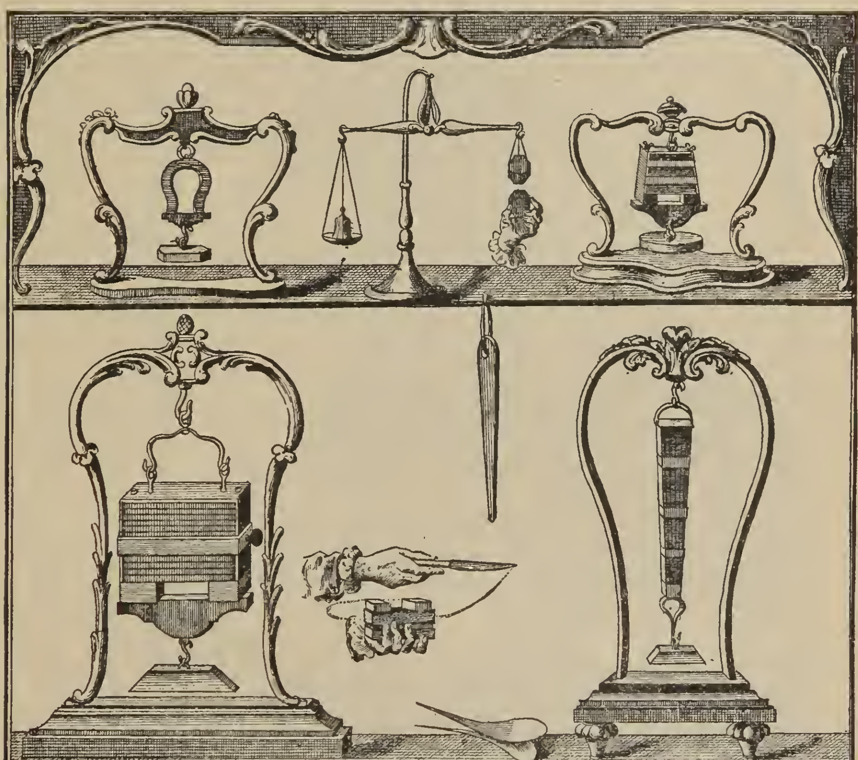


FIG. 4.—ELECTRICITY 150 YEARS AGO.

human hands would ever wield the thunder-bolt or unfold, by the aid of a globe of sulphur, the mightiest principle of nature.

But in the next century electricity sprang at once into startling importance. A series of wonderful discoveries aroused the attention of almost every scientific mind in Europe. England again led the way in the path of investigation. Hawkesbee invented the glass electrical machine,—a great improvement upon that of Guericke; and in 1730 Steven Grey began a course of experiments that unfolded the leading principles of the science.

France took up the study, and the curious discoveries of Dufaye and Nollet excited the wonder of their contemporaries. Dufaye transmitted the electric spark through a cord thirteen hundred feet long; and at length, in conjunction with the Abbé Nollet, he performed an experi-

FIG. 5.—L'ABBÉ NOLLET WATCHING THE EXPECTED DEADLY EFFECT OF A CONTINUAL ELECTRIC CHARGE ON ANIMALS.

ment, with wonder and terror, that seemed the crowning mystery of the science. Dufaye suspended himself by a silken cord, and was then filled with electricity by the abbé. He presented his hand to his companion, half doubting the truth of his own speculations, when a brilliant spark shot from one philosopher to the other, and filled both with an

equal surprise. Never had such a wonder been seen since the days of the Gothic warrior Walimer, who, according to Eustathius, flashed out sparks from his body, or the ancient philosopher who could never take off his clothes without emitting flames of fire.[1]

Not long after, however, an event occurred that seems to have filled Europe with still greater wonder and awe. It was known as the Leyden experiment. Professor Musschenbroek, who wrote an account of it to Reaumer, can scarcely express in language the agitation and terror into

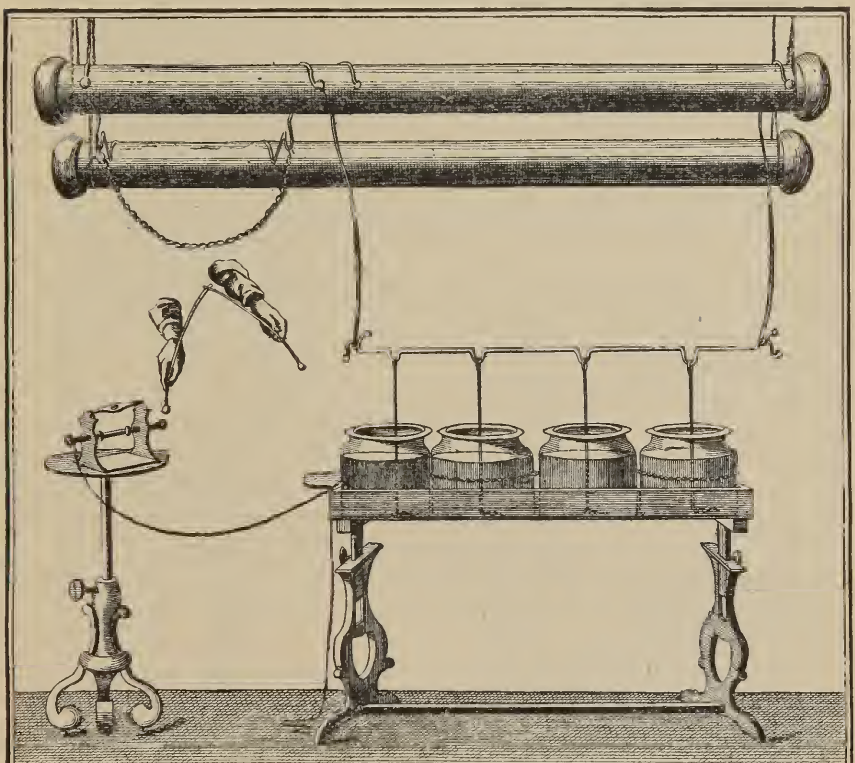


FIG. 6.—BATTERY OF LEYDEN JARS, WITH ACCESSORIES.

which his unheard-of sufferings had thrown him. He had felt the first shock of electricity prepared by human hands, and not the whole kingdom of France, he declared, could induce him to take another. He had been struck in the arms, shoulders, and breast, and two days elapsed before he recovered from the mysterious blow. The professor, in fact, had invented the Leyden jar. He had been endeavoring for some time to inclose electricity in a safe receptacle, from which it could not escape, except with his permission, and at length succeeded in imprisoning the genie in a glass vessel partly filled with water. Suddenly he formed a

[1] Grey seems to have anticipated the experiment. Priestley's Hist. Elect., i, p. 66.

connection between the two surfaces of the jar.[1] The imprisoned electricity sprang through his body and shook him with a wild convulsion. Novelty added its terrors to the unseen assault; his imagination was filled with an indefinite alarm; he shrank from his glass bottle as if it were tenanted by the devil. Yet we soon after find him recovering his spirits, and once more experimenting upon his powerful instrument. The electric jar was soon employed in all the laboratories of Europe, and everywhere terrified philosophers by the vigor of its shock. One lost his breath, and believed that his right arm was forever disabled; Professor Winkler was thrown into convulsions, and had recourse to cooling medicines to avoid fever; Abbé Nollet received a severe blow: his body was bent, his respiration stopped, and he dropped the glass jar in terror. Yet the shock of the Leyden vial soon became the favorite amusement of court and saloon. It was exhibited before Louis XV at Versailles, and a chain of two hundred persons, having joined hands, received at once the mysterious blow. Each was severely shaken, and it was curious to observe, says a contemporary account, how the peculiar temperament of every individual displayed itself in the moment of terror.[2] Soon itinerant electricians wandered over Europe, astonishing the unlearned and the rustics by administering electric shocks from the Leyden jar; and the mysterious machines became familiar to the people as well as to the court.

The jar was improved by coating its sides with a thin metallic covering; its power was increased; it was used in medicine to revive the paralytic, or to open the lips of the dumb; long sparks were drawn from it that resembled flashes of lightning, and that killed unfortunate little birds. A battery of jars was at length invented by Franklin which gave shocks that reminded one of the terrible power of the thunder-bolt; and the whole scientific world felt that it stood on the brink of some unparalleled discovery.

The Franklin was already born, and his name had now grown great in the science.[3] His mind was of a peculiar cast that recalled the vigorous simplicity of the Greeks. He was a modern Solon, a speculative Thales. He had wandered away from Boston,—a printer's apprentice,—and had found employment and success in Philadelphia. From his parents he had received no inheritance, except the noblest,—a spotless example, a healthful constitution, a sane mind; and, after a vigorous struggle and several failures, the philosophic printer had won the respect and the attention of his fellow-townsmen.

He founded schools, libraries, and various useful institutions in his adopted home, and at 45 had become one of the most useful citizens. Still Franklin lived obscure except to his narrow world, and his eminent

[1] Priestley, i, p. 153.
[2] Académie des Science, 1746, p. 7.
[3] Sparks's Life of Franklin, vol. i, p. 152.

powers had won him no general renown. He had, perhaps, pleased himself in his youth with the hope of excelling in letters; he had formed his style by a careful study of Addison; he wrote clear and sensible essays that showed the purity of his taste and the weakness of his fancy; and

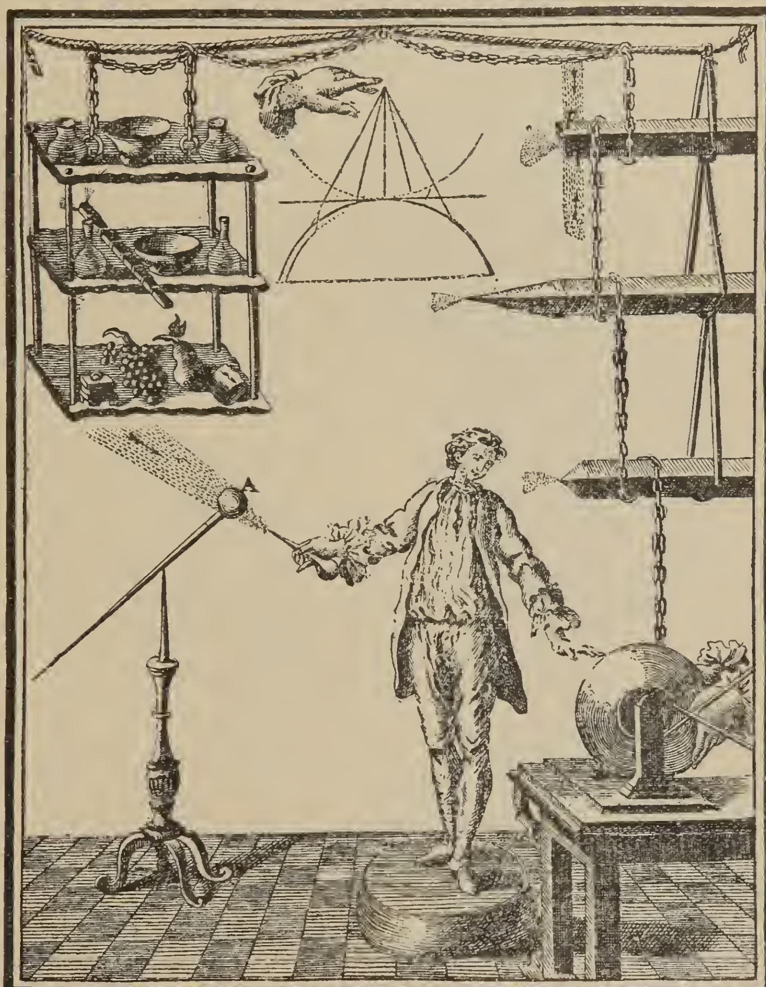


FIG. 7.—ENGRAVING, REPRODUCED FROM NOLLET'S BOOK, SHOWING THE EFFECTS OF ELECTRIC CHARGES UPON EVAPORATION, ETC.

yet, in literature, he had been far excelled in notoriety, if not fame, by his unprincipled companion, Ralph. Franklin's rare humor—the wit of a philosopher—shines out in his "Busy-Body," his "Almanac," his "Ephemera," or his famous "Whistle." He uttered keen apothegms that lived like those of Solon, and sharp satires that want the bitter

hopelessness of Diogenes. But his literature scarcely possessed the shining marks of genius, and was plain, cold, and lifeless. He was an excellent writer, but he was never great.

His genius, like Bacon's, lay in his power of swift induction from moral or physical facts. In morals he was wisest of his contemporaries. He taught young mechanics that "time is money," that "credit is money," and that purity, honesty, and self-respect were better than wealth, luxury, or any other success. His own labors were unceasing; he wrote, toiled, thought incessantly for his fellow-men; he was noted and observed for his modesty and discretion; his acute mind was ever seeking for useful novelty in science and in conduct; and hence, when Franklin came to stand before mankind, covered with his splendid scientific renown and the representative of the new republic that seemed about to receive the classic refinement of a better age, he was received in the courts of Europe as a worthy successor of the philosophers of Athens and Ionia. As Washington appeared before the world clothed in the purity, the probity, the valor of a Fabricius or a Cato, so Franklin was universally compared with the acute sages and philosophers of Greece.

To Franklin electricity owed the most wonderful of all its achievements in the eighteenth century.[1] The obscure provincial observer was led, by an accidental circumstance and his own eager fondness for knowledge, to enter upon the study of the new science. Peter Collinson, a member of the Royal Society, sent over an electrical machine to Philadelphia, and Franklin at once commenced a series of experiments that led to remarkable results. Never, he wrote to Collinson in his first letter, March 28, 1747, had he been so engrossed by any pursuit.[2] All his leisure moments were given to his machine. His fellow-townsmen thronged his rooms to watch his novel researches. His labors were rewarded by constant discoveries, and his wonderful inductive powers soon led him to unfold, in his admirable style, the hidden principles of the science. In 1747 he commenced writing to Collinson, in a series of letters, an account of his researches in electricity. He gave clear directions for the performance of various beautiful or instructive experiments that were wholly new and surprising. He explained the phenomenon of the Leyden jar; he showed how iron points attracted electricity; and, at length, he declared that the lightning and the thunder were produced by the same agent that was inclosed in the mysterious bottle, and he urged the English philosophers to draw down the electricity of the skies by placing iron points upon towers or poles, and thus test the accuracy of his theories. His suggestions, it is related, were received by the Royal Society with shouts of laughter. They refused to print Franklin's

[1] Euler, Dis. de Causa Elect., 1755, p. 27. Idem assernit Franklinus, futuria experimenta animo sagici quasi præmincians. (See p. 132.)

[2] Sparks's Life of Franklin, vol. v, p. 185.

papers in their "Transactions," and they seem to have looked upon his speculations and experiments as scarcely worthy of notice. They thought them the silly dreams of an ignorant provincial.[1]

Fortunately, however, for science and mankind, Collinson was more intelligent, and saw at once the value of Franklin's researches. He published the letters, and they drew the attention of Europe. Buffon read them in France, and persuaded his friend Dalibard to translate them into French; Franklin's rare and beautiful experiments were repeated in Paris; Louis XV and all his court hastened to see them, and were charmed and amazed at Franklin's genius and the wonders of the new science; public lecture-rooms were opened for their performance, and all Paris thronged to the rare exhibition. The letters were translated into many languages, and suddenly the name of the obscure printer in Philadelphia became one of the most renowned in the annals of science. His theories were assailed by the Abbé Nollet and a party of the French philosophers, but they also found many defenders, and a large school of enthusiastic men of science, struck by the vigor of Franklin's genius and the novelty of his discoveries, assumed the name of Franklinists.

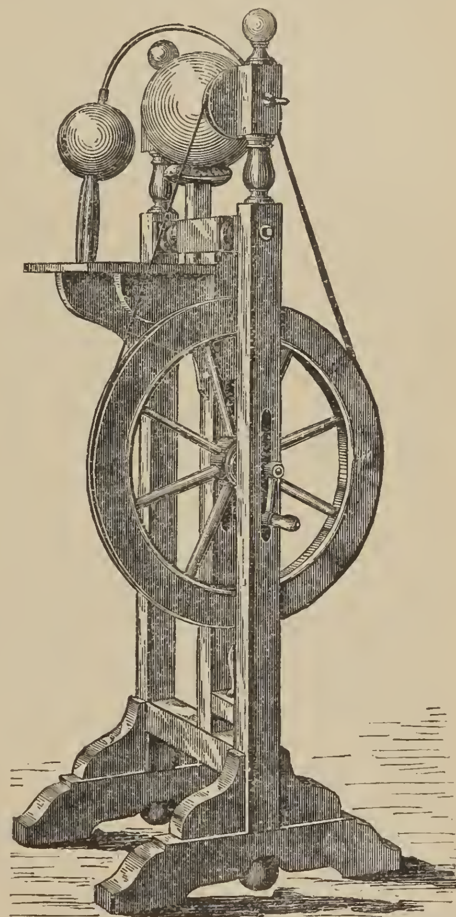


Fig. 8.—Engraving of Benjamin Franklin's Electrical Machine, the Oldest Improved Form for Producing Electricity for Experimental Purposes.

Still, however, Franklin's most daring speculation as to the unity of the electricity of the earth and the air, which had awakened the derision of the whole Royal Society, remained untested by experiment, and the philosophers prepared, with doubt and dismay, to attempt its

[1] Sparks's Life of Franklin, vol. v, p. 175.

verification. He felt that his fame must rest upon his success. If he could draw down the lightning from the skies by presenting his iron points to the thunder-cloud, he must attain a renown that would live forever. If he failed, by the incompleteness of his instruments or any unlooked-for accident, he would seem to merit the scorn which European philosophers were prepared to pour upon him.

Philadelphia, too, offered no convenient tower or steeple on which to fix his iron points; while the modest inquirer was probably anxious that his first experiment should be made with no one present to witness his possible failure.[1] His inventive mind suggested a simple expedient. He formed a common kite from a silk handkerchief stretched upon two crossed sticks; on the upper part was placed the iron point; the string was of hemp, terminating in a short silken cord, and at the end of the hempen string hung an iron key. Such was the simple apparatus with which the philosopher set forth from his home, on a cloudy day in June, 1752, to draw the lightning from the skies; to penetrate a mystery upon which ages had meditated in vain. He took his son with him as the only witness of his secret adventure. As the rain was falling he stood under a shed and raised his kite. It was, no doubt, a moment of strong and unprecedented excitement, and we can well imagine that Franklin watched his kite slowly ascending with a keener interest than Etruscan augur or Roman priest had ever felt as he awaited the omen of the gods. A cloud passed over, no trace of electricity appeared; the heart of the philosopher sank with dismay. But suddenly the falling rain made the hempen string an excellent conductor, and Franklin saw that its fibres began to be stirred by some unusual impulse. He applied his hand to the key, and at once drew sparks from the skies. He felt that he had triumphed; but the first thought of his generous nature, no doubt, was how to make his discovery useful to mankind; and one can scarcely avoid lamenting that no vision reached him, in the moment of his victory, of that wonderful instrument with which another American philosopher has girdled the earth and made electricity the guardian of civilization.

Before his own success, Franklin's theory had already been tested and proved in Europe.[2] The French king, Louis XV, was a strong Franklinist, and urged Buffon and the other philosophers to try the experiment of the iron points, according to Franklin's directions. On the 10th of May, therefore, Dalibard erected a bar of iron forty feet long, at Marly, and succeeded in drawing electricity from a thunder-cloud. It should be remembered, too, that the Abbé Nollet had suggested the connection between lightning and electricity before Franklin wrote; and that the idea had arisen in the minds of other philosophers. Yet Franklin could not have been acquainted with their theories, and no one

[1] Sparks's Life of Franklin, vol. v, p. 175.
[2] Gentleman's Magazine, 1752, p. 229.

before him had ever suggested any means of forming a connection with the thunder-cloud. His theory and his method were altogether original.

Again Europe was startled by a novel thrill of wonder and excitement.[1] The electric sparks of the Abbé Nollet and the famous experiment of Leyden sank into insignificance before the sublimity of the new achievement. Franklin, the modest philosopher of half-savage America, snatching the thunder-bolt from the skies with his kite and key, was the wonder of the hour. Kings became his disciples; princes flew kites in summer showers, and repeated the experiments; Europe was covered by a chain of iron points from Paris to St. Petersburg; and the study of the lightning became as universal as in the days of Etruscan superstition.

Franklin was covered with honors. The Royal Society of London, eager to repair its former neglect, elected him a member and awarded him its highest prize. In France, Russia, Germany, he was still more highly honored; he was the most famous of philosophers. From this time, too, until near the close of the century, the science of atmospheric electricity was studied by eager observers. The thunder-cloud was the favorite subject of learned inquiry. Brilliant hopes of further discoveries were entertained that were never fulfilled; and one eminent philosopher fell a victim to the dangerous research.

Professor Richman, of St. Petersburg, had erected an iron rod in his observatory for the purpose of repeating the American experiments, and ventured too near the instrument; a sudden flash descended the conductor, struck him upon the head, and passed through his body. He fell dead against the wall. He is remembered as the martyr of the science. Professor de la Garde, of Florence, was struck down by an unexpected shock, but recovered.[2] Yet danger seemed only to add new interest to the attractive study. Franklin invented his lightning-rod, which was at once employed to protect the homes and the public buildings of Europe and America; and his disciples were everywhere engaged with kites and points in an effort to disarm the thunder-bolt of its terrors.

The thunder-cloud was mapped out and described by countless observers. Lightning from its different forms was given different names.

Franklin and his innumerable disciples began now to extend their researches over the whole domain of nature, and were rewarded by an infinite number of novel discoveries. Everywhere electricity was found to be capable of explaining mysteries that had long seemed supernatural and almost divine, and of offering attractive theories that served to delight and inspire the fancy, even if they did not wholly satisfy the reason. The auroral lights that danced in lovely variety over the icy

[1] Acad. des Sciences, 1752, p. 9.
[2] Gentleman's Magazine, 1753, p. 432.

fields of the north were believed to be electrical.[1] Castor and Pollux, or the baleful Helen, who had wreathed their spectral forms around the masts of Roman ships, now created to be supernatural; the luminous rains, where every drop seemed a ball of fire, or the strange flames that sometimes hovered over armies as they went to battles, were found to be no more mysterious than the Leyden jar; the fearful roar of the thunder was known to be only the echo of the first discharge among the piles of clouds; the electric fire was traced to the water-spout, the whirlwind, or the crater of the volcano; and the triumphant inquiries at length discovered that the round world itself was only a huge electrical machine, and that all its tenants were constantly influenced by the subtle changes of the electric atmosphere.

It was soon observed that the human body was strongly influenced by the electric discharge; the blood ran quicker, the limbs were stirred, the spirits were excited, the intellect aroused;[2] and enthusiastic physicians recorded wonderful cures performed by the aid of electricity. Had not a panacea been discovered? Was not this strange spiritual substance nearly allied to the source of life? The idea, in the last century, excited a new thrill of expectation and awe. Electricity was applied to various forms of disease, and was afterward found successful in effecting a cure. It augmented the circulation of the blood, increased the pulsations, and improved digestion. The paralytic were healed and made to walk again; the feeble and depressed seemed inspired with new hope. The dumb were made to speak, and the blind see.[3] Bertholon, who wrote a treatise on medical electricity toward the close of the last century, relates numerous instances of cure performed by its aid, and the scientific world was full of hope in the efficacy of their new medicament. The electrical machine, for a time, seemed ready to alleviate the worst forms of human woe. So sanguine are men of coming good, so eager to escape from present pain! Yet the pleasing medical dream soon passed away, and it was found that even the Leyden jar was incapable of repairing the ravages of disease, or of amending those evils which men, by their own excesses, so often bring upon themselves. The dissolute noble still fell down in a paralytic fit from which even the skillful electrician, Abbé Nollet, could never awaken him;[4] the uncleanly city was still full of pestilence; the poor hovel communicated its fevers to the palace.

Electricity of to-day, bridled as it is in the hands of the modern scientist and physician, brings forth more ripened fruits. Many ailments are now amenable to the current where other medical agents have failed. The doctor of this age has done much toward bringing electro-therapy to the front rank of medical science.

[1] De la Rive, Treat. Elect., iii, p. 169.

[2] Bertholon, De l'Électricité du Corps Humain, etc., i, p. 94 *et seq.*

[3] Several cases of dumb persons being cured are related in the papers of the time. See Gentleman's Magazine, 1752 and 1753.

[4] Bertholon, i, p. 440. Nollet was the first to electrify the paralytic.

This medical thunder-bolt (electricity) has passed through many vicissitudes, being at one time recognized and employed at the various hospitals, and then again being thrown aside and left for the most part in the hands of the money-making charlatans and quacks; though, as each new important discovery in this science has been reached, medical men's minds have again turned anew to the subject, and interest in its therapeutic properties has been awakened. But as every tide has an ebb and a flood, so the promises of cure; there have followed failures and disappointments which have thrown the usage of this valuable agent into disrepute, to be again, after a time, reborn and nursed into popular favor. It was during a period of two hundred years in which these alterations have been taking place, in the opinions held of the value of electrical treatment and in the frequency of its employment. Men of science have unceasingly been pursuing their investigations into its wonderful mysteries, properties, and possibilities. New successful research on new research has been their patient reward, and to-day we have arrived at an age when practical electricity is making most rapid strides. We shall see, also, the day when the current will be meted out to the suffering in such dosage as our present remedies are meted. The time has arrived, and another electro-therapeutic cloud is hanging over the medical world again. In the past few years special didactic and clinical departments have been added to the regular college curriculum in many of the foremost institutions. The current is once more called into service to aid in the conquering of the many maladies that physicians and surgeons are battling with. It seems that a general desire has been evinced, both by members of the profession and the laity, for a more thorough knowledge of the benefits to be derived from this agent, electricity, and the best means of securing them.

One of the most astonishing discoveries, to the intellect of this age, was the explanation now given of the wonderful properties of the torpedo and the electric eel. They were soon shown to be natural Leyden jars. The torpedo had been noticed by Aristotle and Pliny, and had long been an object of wonder and superstitious dread to the fishermen of the Mediterranean. But its electric power was feeble compared to the startling shocks conveyed by the gymnotus of the lagoons of Cayenne and South America. Humboldt has given a striking description of the vigor of this most famous of the electric fish.[1] He had been anxious to obtain living specimens of the gymnotus, and employed a number of the natives of the country to engage in the singular fishery. The gymnotus lives in the hot bayous of Cayenne, covered by the thick shade of tropical vegetation and hidden in the muddy waters. It is often more than five feet in length, and its electric shocks are so powerful that no living thing ventures to invade its retreat. Even the Indians are afraid to strike it with harpoons or to catch it with a line, since

[1] Travels, vol. ii, pp. 113, 114.

its powerful discharges benumb their arms and drive them away in terror, while the serpent-like agility of the great eel enables it to elude or destroy their nets. Humboldt, together with a party of natives, approached a lagoon inhabited by the electric monsters. He could not conceive how the Indians were to succeed in taking their prey alive; they told him, to his surprise, that they were about to fish for them with horses. A number of mules and horses were collected on the banks of the lagoon, and the Indians drove them, with blows and loud outcries, into the dangerous waters. A strange battle at once began. The electric eels, roused from their torpor, attacked the unfortunate invaders, fastening upon the lower parts of their bodies and giving them a succession of almost fatal shocks. Benumbed, terrified, and fainting, they strove to fly from the dangerous pool, but the Indians drove them back again with wild cries and sharp blows, and the combat was renewed. The huge eels were seen rushing to assail their foes with fresh vigor, and the savages, clinging to the overhanging trees and bushes, forced the horses into the midst of the water; and at length, in a few minutes, the battle was decided, and several of the horses sank and were drowned. "The contest," says Humboldt, "between animals so different in organization, in so strange a place, presented a most picturesque spectacle." It must certainly have been a painful one. And now the victorious eels, having exhausted all their electricity, crept languidly toward the shore, where they were taken with small harpoons fastened to dry lines. So completely was their power lost that the Indians did not receive a shock. Humboldt secured several eels, but little injured, more than five feet long, and he was told that they were often much larger. It is a peculiar trait of the electric animals that they are produced in water,—an excellent conductor,—and that, by some natural provision, they can discharge or retain their electricity at pleasure.

Philosophers now began to explain them with attention, and to form theories as to the source of their action. But the production of animal electricity seems capable of being explained only by those later theories which were soon to enlarge and adorn the science.

Thus the eighteenth century had elevated electricity into one of the most important and attractive branches of knowledge; it was reserved for the nineteenth to apply it practically to the benefit of mankind. In all his brilliant and thoughtful experiments, Franklin had often sighed over their apparent uselessness: he would have been amply satisfied could he have foreseen how powerful an agent his favorite science was destined to become in advancing manufactures and the arts, and in binding nations together by an almost instantaneous exchange of thought.

Galvanism, the next great step in electrical progress, was discovered by Galvani, Professor of Anatomy at Bologna, about the year 1790.[1]

[1] Becquerel, vol. i, p. 83. See report Historique sur les Progrès des Sciences Mathematiques, Paris, 1810, p. 224.

A circumstance so accidental as the slight illness of Madam Galvani gave rise to this important event. Her physician had recommended her to a diet of frog-broth, and several of the animals, prepared for the cook, chanced to lie on a table near an electrical machine. One of Galvani's assistants drew sparks from the conductor, and Madam Galvani was surprised to observe that when he did so the muscles of the frogs were distorted and assumed the appearance of life. She called Galvani to notice the strange circumstance. The experiment was repeated with success, and the philosopher, who knew little of electricity, but was a careful anatomist, believed he was on the brink of discovering the principle of life. He entered with strange ardor upon the new research. He experimented incessantly upon muscles and nerves. At length he found that muscles and nerves were thrown into the singular convulsion by the mere presence of two different metals, and had discovered by accident the principle of galvanism,—the source of the magnetic telegraph or the calcium light.

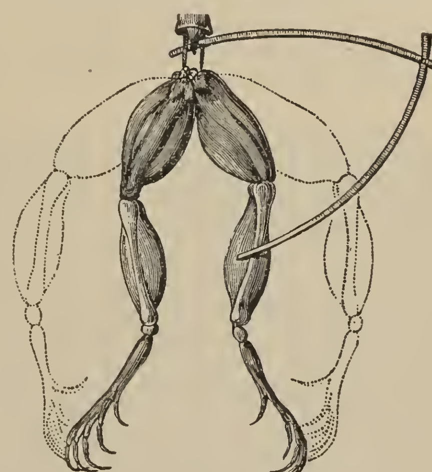


FIG. 9.—EXPERIMENT WITH FROG.

Still, however, Galvani persisted in his scientific delusion that he had unfolded the origin of being. He insisted that the muscles and the nerves created the electric action. He overlooked the effect of the two metals. His disciples were soon numerous, and all Europe was again aroused into excitement by the unparalleled disclosures that philosophy seemed about to make.

Electricity had but lately been drawn down from the clouds; the whole earth was shown to be electric; with one stride more the daring science might unfold the whole mystery of being. But, fortunately for its success, galvanism was taken from the control of its speculative discoverer, and fell into more practical hands. Volta, Professor of Natural Philosophy at Como, an excellent electrician, assailed the theory of his colleague, and showed that the galvanic action came from the two metals, and not from the nerves. A violent controversy raged between the Bolognese school of Galvani and the followers of Volta, and the important question of the origin of life was discussed by the philosophers and the people while Napoleon was preparing to cover Europe with carnage, and while the horrors of the Parisian massacres were yet fresh in every mind. The "reign of terror" which had been commenced in France was about to

extend over all European civilization when the two Italian philosophers were marshaling their disciples in a vigorous intellectual combat. Volta was victorious, and his peaceful triumphs will outweigh a thousandfold, in its beneficial consequences, the disastrous successes of Napoleon.

In the year 1800, a memorable epoch in the history of electricity, Volta announced to the world, in a letter to Sir Joseph Banks, his invention of a wonderful machine. It was composed of alternate sheets or layers of zinc and copper, separated from each other by discs of wet cloth. Two streams of electricity, one negative and the other positive, were found to flow from either pole of the instrument, and its intensity could be increased apparently without limit by enlarging the number of layers. He had invented a voltaic pile. Its form was afterward changed by substituting cups of zinc instead of layers, and Volta formed a beautiful apparatus called " La Couronne de Tasses," the model of all those

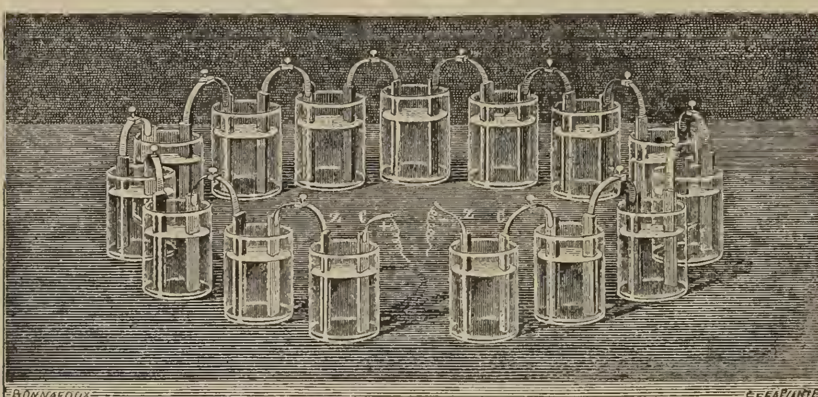


Fig. 10.—Couronne de Tasses.

powerful instruments by which the electric current is dispatched on its useful mission from New York to San Francisco, or taught to fathom the once impassable Atlantic. The wonderful vigor of the new agent became at once apparent. The sharp sparks of Franklin's electrical machine, and even the condensed shock of the Leyden jar, so long the terror of philosophers, were found to be faint and inefficient compared with the mighty electric current that flowed with silent strength from one wire to the other of the voltaic pile. Its effect on the human frame revived Galvani's notion of the principle of life. When the hands of the operator were applied to the opposite poles, instead of a sudden shock he found himself held in the grasp of an invisible power. A series of strong convulsions ran through his arms and shoulders. Scarcely could he withdraw his hands and free himself from his captor. If the instrument were applied to the forehead, a brilliant light flashed over the sight, even though the eyes were closed. The glow-worm touched by the current

shone with increased splendor; the grasshopper chirped as if excited by a stimulant. But when the pile was applied to the trunk of a decapitated body, a most horrible and unheard-of phenomenon occurred. Never had such a spectacle been witnessed before since the age of miracles. The dead body rose from its recumbent position; its arms moved as if to strike in its rage objects in its vicinity; its breast heaved, its legs recovered their strength; and life was imitated or renewed in its fearful actions. Such were some of the tales told over Europe of the powers of the voltaic pile.

It was an age of excitement. Napoleon, the young conqueror of Austria and Italy, now ruled as First Consul at Paris. The revolution had died to give place to a reign of war and violent convulsion; and Napoleon, the centre and source of the impending disturbance, yet always eager for scientific novelty, invited Volta to Paris to explain his new instrument.

In 1801, crowned with his peaceful victory, the Italian philosopher visited the republican court. At three meetings in the Academy of Sciences, in the presence of Napoleon and the most famous philosophers of France, Volta lectured upon his incomparable discovery. He was crowned with the highest honors of the institute; Napoleon loaded him with gifts and attentions, selected galvanism as his favorite branch of science, and offered a reward of sixty thousand francs to him who should produce in electricity or magnetism an impulse equal to that which had followed the invention of the voltaic pile, or the startling experiment of Franklin.

Of all the excitements of the age none stirred the intellect more strongly than Volta's theories. The voltaic pile was believed to be the frame-work of the living organization. Napoleon and his philosophers were struck and impressed by the wonderful idea. "It is the image of life!" said the imperious young conqueror, as he once watched some remarkable experiments.[1] The brain was supposed to be an electric pile, the nerves and muscles the conductors of opposing currents, and the slow beating of the heart the effect of their united action. In moments of fierce excitement positive electricity flashed from the eyes and stirred the nerves; in periods of repose the negative controlled the system. Rage, valor, and achievement were positive; submission and cowardice the current from the opposite pole. On the battle-field the fierce conqueror, a terrible voltaic battery, flashed forth his electric currents in fatal profusion; his opponent yielded because his galvanic vigor had declined. The world dreamed wildly over the new machine, and men, with their usual vainglorious presumption, believed themselves gods.

The dreams were swiftly dispelled; but a series of valuable discoveries followed rapidly the invention of the voltaic pile. The first twenty years of the present century were made illustrious by the achieve-

[1] Lardner, vol. i, p. 113.

ments of the new machine. A splendid throng of eminent chemists and electricians sprang up under its influence, and pursued with intense labor and wonderful discoveries the path pointed out by Volta and Galvani. France, England, Germany, Europe, and America united in advancing the science; and the names of Oersted and Ampère, Davy and Wollaston, Berzelius and a great company of men of genius, scarcely inferior to their leaders, won a renown in their peaceful pursuit that shines with a softened glory amidst the fierce military excitement of that troubled age. Of these men Humphry Davy was perhaps the most conspicuous. Poet, thinker, philosopher, Davy finally concentrated all the great powers of his intellect upon the study of the voltaic pile. He used it to unfold the deepest mysteries of nature. He discovered its wonderful strength, and developed all its resources. Suddenly the most solid and least fusible substances in nature were found to melt away into gases before the steady flow of the galvanic current. Water resolved itself into its gaseous elements. The alkalies liquefied and left behind them their metallic bases. New metals were discovered whose existence had never been suspected. A tremendous heat was produced that burned gold and silver as easily as paper, and that even fused the firm platinum.[1] A magnificent light was produced by burning potash, such as man had never created before. The diamond was melted; the various earths dissolved; the composition of the air investigated; and it was believed that all the geological changes of the surface of the globe were to be attributed to galvanic action. In fact, chemistry became almost a new science under the reforming influence of the voltaic pile; and the brilliant researches of Sir Humphry Davy and his associates astonished their age by their singular novelty and their rare value to the artist and the machine.

Thus the dawn of the nineteenth century might seem to have been almost consecrated to the study of the electric forces. Yet it was also a period of unusual intellectual excitement; and while Davy, Oersted, Ampère, and their associates were startling the world by a succession of wonderful discoveries, the literary atmosphere resounded with the strains of a new school of poetry. Byron, Moore, Coleridge, Wordsworth, and Keats poured forth the language of passion or of reflection to countless readers, and literature united with science in aiding the progress of thought.

At length, in 1820, Oersted, by a remarkable experiment, found the indissoluble union between magnetism and electricity. The magnet, as well as the electron, had long been one of the chief mysteries of nature. Thales had observed its attractive properties, and had supposed that it was endowed with a soul. The Chinese and the Arabs knew that the magnetized needle invariably pointed to the north, and had employed it to guide their journeys by land or sea. Its variations were observed by Columbus, and studied with attention by the early Dutch and English

[1] Lardner, i, p. 133.

navigators. Its connection with electricity had for some time been suspected, and Franklin magnetized a needle by an electric discharge.

But it is to Oersted that we owe the grand experiment by which it was shown that the motion of the magnet depended upon galvanic currents. He showed that a magnetized needle was deflected or controlled by the passage of the electric fluid along a wire. The discovery produced a new ardor in every scientific mind. Ampère, Arago, Davy, Faraday, and Henry enlarged upon the thought; powerful magnets were formed by passing the voltaic fluid through a wire bound in spiral folds around an iron bar, and the principal ones at length discovered upon which rests the crowning achievement of electricity,—*the magnetic telegraph!*

We have now traced, though very briefly, the progress of knowledge of electricity, from the germ of the science which lay hidden for thousands of years in amber, like the insects so often found in that substance,—and yet unlike them, for it possessed immortality,—up to the first practical application of that knowledge to human use and benefit. The lightning had been caged. The mighty force, which since the creation of mankind had aroused but feelings of awe and terror, could now be confined and examined, or diverted at will from its path of destruction. The wise men of the eighteenth century had captured the electrical Pegasus; it remained for the wiser men of the nineteenth century to yoke him to the plough.

It is the most poetical of the sciences, as well as the most practical. Its future is full of promise, and no one can safely affirm that it may not yet achieve discoveries more wonderful than any in the past, and produce a still more beneficial effect upon the progress of man. Yet its earlier cultivators can never be forgotten, and the gratitude of their race must always attend those laborious intellects whose endless toil snatched the thunder-bolt from the skies and made it the useful servant of modern civilization.

Electrical Measurement.

Twenty-five years ago the experimental sciences of electricity as well as magnetism were, in great measure, mere collections of qualitative results, and, in a less degree, of results quantitatively estimated by means of units which were altogether arbitrary. These units, depending as they did on constants of instruments and conditions of experimenting which could never be made fully known to the scientific public, were a source of much perplexity and labor to every investigator, and to a great extent prevented the results which they expressed from bearing fruit to the furtherance of scientific progress. Now, happily, all this has been changed. The absolute system of units introduced by Gauss and Weber, and rendered a practical reality in England by the labors of the British Association Committee on Electrical Standards, has changed experi-

mental electricity and magnetism into sciences of which the very essence is the most delicate and exact measurement, and enables their results to be expressed in units which are altogether independent of the instruments, the surroundings, and the locality of the investigator.

The record of the determinations of units made by the members of the committee, for the most part of the methods and instruments which they themselves invented, forms alone one of the most interesting and instructive books[1] in the literature of electricity, and, when the history of electrical discovery is written, the story of their work will form one of its most important chapters. But besides placing on a sure foundation the system of absolute units, they conferred a hardly less important benefit on electricians by giving them a convenient nomenclature for electrical quantities. The great utility of the practical units and nomenclature which the committee recommended soon became manifest to every one who had to perform electrical measurements, and has led, within the last few years, to their adoption, with only slight alterations, by nearly all civilized nations. Although it is only five years since the recommendations[2] of the Paris Congress of Electricians were issued, they have been almost universally adopted and appreciated by those engaged in electrical work, and have thus begun to yield excellent fruit by rendering immediately available for comparison, and as a basis for further research, the results of experimenters in all parts of the world.

But in order that the full benefit of the conclusions of the Paris Congress may be obtained it is essential, in the first place, that convenient instruments should be used; adapted to give directly, or by an easy reduction from their indications, the number of ampères of current flowing in a particular circuit, and the number of volts of difference of potential between any two points in that circuit. To be generally useful in practice these instruments should be easily portable and should have a very large range of sensibility; so that, for example, the instrument which suffices to measure the full potential produced by a large dynamo-electric machine may be also available for testing, if need be, the resistance of the various parts of the armature and magnets by the readiest and most satisfactory method, namely, by comparing, by means of a galvanometer, a high resistance of difference of potential between the two ends of a known resistance joined up in the same electrical circuit. In like manner the ampère measure should be one that could be introduced without sensible disturbance into a circuit of low resistance to measure either small fractions of an ampère or the whole current flowing through a circuit containing a large number of electric lamps. These conditions are more or less fulfilled by a large variety of practical instruments recently patented by different inventors.

[1] Report of the British Association Committee on Electrical Standards. Edited by Professor Jenkin, F.R.S.

[2] See Appendix, in book on Absolute Measurements in Electricity and Magnetism, by Andrew Gray, M.A., F.R.S.E., for practical units, as adopted by the British and Paris Associations. London: Macmillan & Co.

Almost every branch of science nowadays has its own language, made up of its technical terms, which in time become absorbed even into general speech. This is already fast becoming the case with the language of electricity. Ampères and volts and ohms are no longer possessed of meaning only to the initiated, but are taking their place among such every-day standards as pounds and gallons and inches. Although this chapter has none of the pretensions of a treatise, it is my aim to devote it to a plain statement of the principles of electrical measurement and the uses of the most important forms of the galvanometer.

There is no force in nature more subject to the inevitable laws of the great mother than electricity; and many of these laws, and these measurements dependent upon them, are so simple as with little study to be readily mastered. Just as in the ordinary arithmetical standard we employ weights and measures, so we may in the application of electricity employ various measurements for various purposes.

As, also, we commonly employ suitable instruments and apparatuses in weighing and measuring tangible substances, using scales or balances for those bought and sold by weight, tape-measures and miles for measurements, and clocks and watches to mark the advance of time, so we find it essential, in the valuations and comparisons of electricity, to use suitable instruments.

These instruments are named galvanometers, and are used to measure, compare, and estimate many of the different properties and magnitudes of electricity. By their aid we may readily ascertain and compare the working strength and value of electric currents, the resistance which electro-magnets, wires, and other conductors offer to the passage of the current, the electro-motive force or initial power, and the resistance of batteries, etc. Farther on we shall speak in full of the galvanometer, etc.

Definitions of Electrical Terms and Units.—In order that the galvanometer be clearly understood, as well as when, why, and how to use it, it is proper that at the outset we should at least have some comprehension of the meaning of the terms commonly used in expressing the different properties, magnitudes, functions, and relations of electricity and electrical conductors, and of the units which indicate the value of such properties.

In the part of this work on "General Remarks upon Batteries," I have already given in detail, and shown by means of experimental illustration, some of these electrical terms, such as electro-motive force, potential, resistance, joint resistance, internal resistance, etc.

Units of Electrical Measurements.—We know now, by what has been seen, that the batteries by which electricity is developed, the conductors by which it is transferred, the instruments by which it is made useful, and the electric current itself have certain properties, magnitudes, or qualities which it is often necessary to measure in order that their working value may be properly estimated.

In order to make such measurements and to state their results, it is essential that there should be some standard terms or units, which, when expressed, will convey to the mind definite ideas, precisely as in measuring a distance, etc.

Furthermore, when one substance has several properties or magnitudes, a different system of measurement is required for each magnitude; for, as in a cubic block of wood we should measure one of its sides by superficial measure, its contents by cubic measure, and its weights by still another system, and would state the results differently in each case, so the different electrical magnitudes have their own opposite and separate units in which the results are expressed.

Sometimes it is found that the results of certain measurements are obtained by reference to several different magnitudes; as, for example, when the time is taken of the speed of a horse, or a locomotive, we take the length of the distance traversed and the time consumed in traveling that distance, and so calculate the velocity by reference to both space and time. In certain electrical measurements we find it necessary to resort to the same process, and to combine different units to obtain a definite result.

The names of distinguished electricians and scientists have been given to the practical electrical units. Thus the unit of electro-motive force is called the "volt," from Volta; and the unit of resistance the "ohm," after Ohm, the German physicist and mathematician; while the unit of current-strength is named the "ampère," after the French philosopher.

An Analysis of the Arithmetical Electrical Terms.—Space is the lineal distance from one point to another.

Time is the measure of duration.

Force is any cause of change of motion of matter. It is expressed practically by grammes, volts, pounds, or other units.

Resistance is a counter-force or whatever opposes the action of force.

Work is force exercised in traversing a space against a resistance or counter-force. Force multiplied by space denotes work as foot-pounds.

Energy is the capacity for doing work, and is measurable by work units.

Mass is quantity of matter.

Weight is the force apparent when gravity acts upon mass. When the latter is prevented from moving under the stress of gravity its weight can be appreciated.

Physical and mechanical calculations are based on three fundamental units of dimension, as follow: the unit of time, the second,—T; the unit of length, the centimetre,—L; the unit of mass, the gramme,—M. Concerning the latter, it is to be distinguished from weight. The gramme is equal to one cubic centimetre of water, under standard conditions, and

is invariable. The weight of a gramme varies slightly with the latitude and with other conditions. Upon these three fundamental units are based the derived units,—geometrical, mechanical, and electrical. The derived units are named from the initials of their units of dimensions, the C. G. S. units, indicating centimetre, gramme, second units.

In practical electrical calculations we deal with certain quantities selected as of convenient size, and as bearing an easily-defined relation to the fundamental units. They are called practical units.

The cause of a manifestation of energy is force; if of electro-motive energy,—that is to say, of electric energy in the current form,—it is called electro-motive force (E. M. F., or simply E.), or difference of potential (D. P.). What this condition of excitation may be is a profound mystery, like gravitation and much else in the physical world. The practical unit of electro-motive force is the *volt*, equal to one hundred millions (100,000,000) C. G. S. units of electro-motive force. The last numeral is expressed more briefly as the eighth power of 10, or 10^8. Thus the volt is defined as equal to 10^8 C. G. S. unit of electro-motive force.

This notation in powers of 10 is used throughout C. G. S. calculations. Division by a power of 10 is expressed by using a negative exponent, thus 10^8 means $\frac{1}{100000000}$. The exponent indicates the number of ciphers to be placed after 1.

When electro-motive force does work, a current is produced. The practical unit of current is the ampère, equal to $\frac{1}{10}$ C. G. S. unit, or 10^1 C. G. S. unit, $\frac{1}{10}$ being expressed by 10^1.

A current of 1 ampère passing for one second gives a quantity of electricity. It is called the *coulomb*, and is equal to 10^1 C. G. S. unit.

A coulomb of electricity, if stored in a recipient, tends to escape with a definite electro-motive force. If the recipient is of such character that this definite electro-motive force is 1 volt, it has a capacity of 1 *farad*, equal to $\frac{1}{1000000000}$, or 10^9 C. G. S. unit.

A current of electricity passes through some substances more easily than through others. The relative ease of passage is termed conductance. In calculations its reciprocal, which is resistance, is almost universally used. A current of 1 ampère is maintained by 1 volt through a resistance of 1 practical unit. This unit is called the ohm, and is equal to 10^9 C. G. S. unit.

Sometimes, where larger units are wanted, the prefix *deka*, ten times; *heka*, one hundred times; *kilo*, one thousand times; or *mega*, one million times, is used,—as *dekalitre*, ten litres; *kilowatt*, one thousand watts; *megohm*, one million ohms.

Sometimes, where smaller units are wanted, the prefix, *deci*, one-tenth; *centi*, one-hundredth; *milli*, one-thousandth; *micro*, one-millionth, are used. A *micro-farad* is one-millionth of a farad.

Practical Units.—Electro-motive force is measured in volts. A

volt is very nearly the pressure yielded by a certain standard galvanic cell, usually the Daniell, to be described later in this work. The term has also a very accurate mathematical signification.

The "volt" is the unit of electro-motive force, and has very nearly the same value as a single cell of the Daniell battery. Its precise value is 9268 of a Daniell cell in good condition; in other words, the Daniell cell is equal in electro-motive force to one volt and seventy-nine thousandths—1.079. The volt is equivalent to the electro-motive force required to produce a current of the strength of 1 ampère in a circuit having a total resistance of 1 ohm.

The electro-motive force of most of the gravity batteries is almost the same as that of the Daniell, and the electro-motive force of the Leclanché cell is 1.481, or one volt and four hundred and eighty-one thousandths.

OHM'S LAW AND ITS EXPLANATION.

The law showing the relation between electro-motive force, resistance, and current was enunciated by Dr. G. S. Ohm, and is known as Ohm's law. This is the fundamental law of electricity in motion.

Consequently, there are three things about any electric current to be known, namely: its electro-motive force, or pressure; the resistance which it encounters; and the strength of the current, which depends upon these.

We measure steam- or water- pressure in pounds per square inch, heat by thermometric degrees, distances by feet and inches, and so on.

The Ohm.—The standard unit of resistance, which we call the "ohm," may be defined as a resistance about equal to that offered by a wire of pure copper one-twentieth of an inch in diameter and two hundred and fifty feet long, or it may be compared to one-sixteenth of a mile of copper wire, No. 4½ Birmingham wire gauge, which is twenty-three hundredths of an inch, or nearly a fourth of an inch in diameter. It is also approximately equal to a piece of No. 35 copper wire between seven and eight feet long. A mile of No. 12 galvanized-iron wire has an average resistance of about 32 ohms.

The mark which may usually be found stamped on the base of a relay denotes the resistance of the coil from one binding-screw to the other. If, for example, we have a relay marked 100 ohms, we know that that is the measured resistance of the two spools, and that it is equal to about three miles of No. 12 galvanized-iron wire.

THE OHM'S LAW-GIVING SPECIFIC VALUE.

Thus, the strength of current in ampères flowing through a circuit is equal to the number of volts of electro-motive force divided by the number of ohms of resistance in the entire circuit. The strength of current is ascertained by taking the electro-motive force in volts and

dividing that number by the total resistance of the circuit, including that of the battery, wires, and instruments, in ohms. The result will be in ampères, or fractions thereof.

Let us follow this problem out. A battery having an electro-motive force of 50 volts and an internal resistance of 75 ohms is connected in circuit with a galvanometer having a resistance also of 10 ohms. The total resistance in the circuit is that of the battery, galvanometer, and wire added together, *i.e.*, 160 ohms. To find the strength of current we divide the 50 volts by the 160 ohms, which gives us a quotient of 0.3125 ampère, or 312½ milliampères.

Therefore, if we know the electro-motive force and resistance of any circuit, we can easily figure out the strength of current. On the same principle, knowing the electro-motive force in volts of a battery, and the current in ampères produced thereby in a given circuit, we can ascertain the resistance of that circuit, including that of the battery, by dividing the electro-motive force by the current. Likewise, the value of electro-

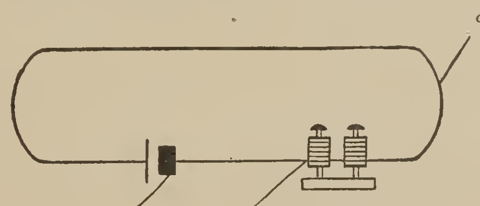


FIG. 11.
a, battery; *b*, electro-magnet; *c*, connecting wire.

motive force may be obtained if we know that of the current and of the total resistance of the circuit; for if we multiply the resistance in ohms by the current-strength in ampères, we find the value of the electro-motive force in volts.

The Ampère.—The unit of current-strength was, until very lately, called a "weber," but is now called the ampère, after the French physicist of that name. The ampère may be defined as the strength of a current produced in a circuit having a total resistance of 1 ohm by an electro-motive force of 1 volt.

Let us explain it in the following way: If a circuit consisting of one cell of a battery, an electro-magnet, and the necessary connecting wires, as in the above diagram,—the battery, we will suppose, having an electro-motive force of 1 volt and an internal resistance of $\frac{1}{3}$ ohm,—the electro-magnet and connecting wires also have a resistance of $\frac{1}{3}$ ohm each, making a total resistance of 1 ohm in circuit.

The current flowing in this circuit will have a strength of 1 ampère. A milliampère is one-thousandth of an ampère, and is made use of in computing currents of comparatively feeble strength. This last unit of current-strength is used in medical electricity.

To recapitulate in briefer terms, electro-motive force means electrical pressure. Resistance has its obvious meaning. Electro-motive force is not measured in pounds per square inch like steam- or water- pressure, but in volts; and a volt is the pressure given by one standard cell.

Resistance is measured in ohms, and an ohm answers to the resistance offered by four hundred and sixty feet of ordinary telegraph-wire. Approximately, strength of current is measured in ampères. Speaking of a water-wheel, we say we need current flowing at the rate of so many gallons per minute to drive it; speaking of an electric lamp, we say we need a current of from 1 to 50 ampères to keep it glowing. The term "*coulomb*" is a unit current or ampère which transmits the unit quantity of electricity in one second. The unit of electric quantity is called a coulomb; and just as the unit flow of water through a pipe might be taken as that which allowed one gallon of water to pass any point in the pipe during one second of time, so the ampère is the strength of current—the rapidity of flow—which allows 1 coulomb to pass any point in the circuit during one second; so that if a constant current of 1 ampère has been flowing for one hundred seconds in a circuit, then we know that 100 coulombs of electricity have passed any point in the circuit during that time. This unit is far less employed in practice than any of the others, but it may be, in the end, the most familiar of all; for, as electro-therapists, we must sooner or later realize the necessity of measuring the quantity of electricity we give our patients, just as we do any other remedy in our pharmacopœia; and when the electric light comes into more general use in dwellings we shall pay for our electrical supply at so much per thousand coulombs, as we pay for gas at so much per thousand cubic feet.

Tables of Resistances and Conductivity.—It has been already stated that the resistance of a conductor depends upon its dimensions and the matter that composes it. Matthiessen, taking copper, found the following values :—

Metal.	Specific Resistance.
Silver,	0.77.
Gold,	1.38.
Aluminium,	2.29.
Zinc,	2.82.
Iron,	5.36.
Tin,	6.76.
Platinum,	7.35.
Lead,	9.96.
German silver,	10.09.
Antimony,	18.07.
Mercury,	47.48.
Bismuth,	64.52.
Graphite,	1106.00.
Gas-carbon,	2037.00.

From this table we learn that, of all metals, silver offers the least

resistance. We can easily arrange a table of conductivity by taking the reciprocals of the foregoing :—

Metal.	Specific Conductivity.
Silver,	100.00.
Copper,	77.43.
Zinc,	27.39.
Iron,	14.44.
Platinum,	10.53.
Lead,	7.77.
Mercury,	1.03.
German silver,	7.67.
Graphite,	0.0693.
Gas-coal,	0.0386.

The relative conductivity of the principal liquids used in batteries may be seen from the following values found by Becquerel (conductivity of silver = 100,000,000) :—

Liquid.	Conductivity.
Copper sulphate (a saturated solution),	5.42.
Ordinary salt " " "	31.52.
Copper nitrate " " "	8.99.
Zinc sulphate " " "	5.77.
20 c.c. of H_2SO_4 in 220 c.c. water,	88.68.
Nitric acid,	93.77.

Resistances of liquids at different stages of concentration may be seen from the following table by Wiedemann (resistance of platinum = 1) :—

Sulphuric Acid Contained in 100 C.c. Water.	Resistance.
3.7 grammes,	499,000.
5.9 "	283,500.
11.42 "	147,200.
22.82 "	88,070.
45.84 "	79,560.
74.83 "	108,300.
183.96 "	508,000.

With salt solutions the resistance diminishes as the amount of salt increases, the conductivity of pure water being very small. The behavior of sulphuric acid is peculiar. Up to a certain point resistance diminishes with the increase of concentration, but beyond this point resistance increases with further concentration.

The influence of temperature upon a liquid may be seen from the following table, after Wiedemann. The liquid tested was formed by solution of 187.02 grammes of copper sulphate in 1000 cubic centimetres of water :—

At 20.2° C.,	the resistance = 1,907,000.
At 26.2° C.,	" " = 1,715,000.
At 37.5° C.,	" " = 1,419,000.
At 51.5° C.,	" " = 1,163,000.
At 60.0° C.,	" " = 1,047,000.
At 75.6° C.,	" " = 894,000.

The resistance diminishes as the temperature increases, a result which is exactly opposite to what occurs with metals. Müller found the following values for copper wire at different temperatures:—

At 21° C.,	the resistance	= 864.
At a dull-red heat,	" "	= 2100.
At a red heat,	" "	= 2450.
At a bright-red heat,	" "	= 3300.
At a white heat,	" "	= 4700.

When the wire was again cooled to 21° C. its resistance was 910.

Conductivity for carbon increases with the temperature, thus agreeing with the action of liquids. Professor Ayrton thinks this seems to indicate that carbon may be a compound, and not an element. Mercury follows the other metals; that is, conductivity decreases and resistance increases with temperature.

The Wheatstone Bridge is the differential resistance measurer. This instrument is fully described by Wheatstone, its inventor, in the "Transactions of the Royal Society," 1843. This bridge, or also called electrical balance, is usually constructed in this manner: Upon a piece of well-seasoned board, *M*, are placed three strips of thin brass or copper about half an inch in width, which are fastened as shown at *A*, *B*, and *D*, a break being left at both ends of *A*, and also between *B* and *D*. From *B* to *D* a thin German-silver wire, which should be uniform in thickness and free from flaws, is stretched and soldered to the brass or copper strips at each end. Underneath this wire a paper scale, accurately divided into a thousand parts, is placed. Should the length of the wire be, as is usually the case, a metre, the divisions will, of course, be millimetres, but there is no necessity for the wire to be of any definite length; all that is required is that it should be accurately divided, the measurements to be taken from it being not absolute, but comparative. German-silver wire is usually employed because its conductivity is but little affected by variations in temperature. An ebonite block, provided with a metal pin, is made to slide along the board and is connected with a wire, the other end of which may be attached to one pole of the battery or to a galvanometer. The metal pin is usually provided with a spring, so that it may be pressed down upon the wire or not, at pleasure, thus forming a ready means of making or breaking the circuit. To the middle of the strip of copper, *A*, a binding-screw is attached, and to this is fastened one of the battery wires. Binding-screws are also attached to the two ends of *A*, and to the adjacent ends of the side-strips *B* and *D*. In these binding-screws strips of wire, r' and n_3, can be placed so as to fill up the breaks between the side-strips and the ends of the longitudinal strip. *A*, *B*, and *D* are connected with a delicate astatic galvanometer, *G*. This being the construction of the Wheatstone bridge, its mode of action will be, perhaps, better understood by the following diagrams and demonstrations:—

It was found necessary, in experimenting with thousands of miles of cable or insulated wires, to adopt some standard point, in order to ascertain exactly the resistance of the whole. The matter was put into the hands of a committee of the British Association, who determined that an English mile of pure copper wire, No. 16, should be the B. A. unit; they further constructed a wire of silver and platinum, because it was little affected by temperature, which they deposited as the standard of comparison, and this length of wire they estimated in figures to be 13.59 of the length of the copper wire. Bobbins upon which hundreds and thousands of miles of copper wire, No. 16, would have to be wound would be too bulky and cumbersome to manage; it has, therefore, been arranged that German silver, an alloy of about 60 parts of copper with a fraction of lead, 25 of zinc, and 15 of nickel, should be employed, because it has about thirteen times less conducting power than the same-sized copper wire; consequently the standard unit would be represented as follows: B. A. unit of German-silver wire equals 13.59 of an English mile. The bobbins having 13.59 of an English mile of German-silver wire wound upon them represent, therefore, a resistance equal to one mile. The following physical law is the outcome: The resistance of a conductor of any given metal is *directly proportional to its length, and inversely proportional to its thickness*, or cross-section.

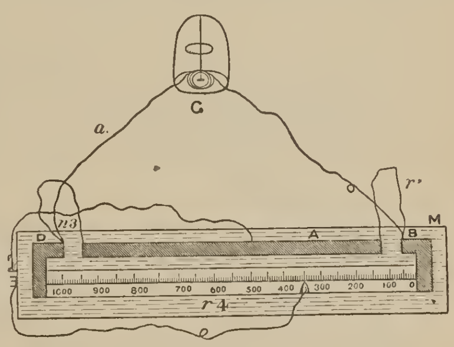


FIG. 12.—WHEATSTONE BRIDGE.

In order to demonstrate clearly the practical value of the Wheatstone bridge, inasmuch as it is so often difficult to thoroughly comprehend its construction and the principles underlying it, I append the following diagrams, with a brief demonstration[1] :—

For the sake of simplicity the brass bands and brakes only are shown. The galvanometer is supposed to be resting in the middle of the board, the battery on the right, and the connecting-key on the left.

For the sake of discussion, it is supposed that the current coming from the battery, *Ba*, is represented by twelve parts; these, on arriving at *P*, split or divide into equal parts; six go in the direction, *A′*, and six in the other, *A*.

The two currents represented by arrows both pass through equal

[1] These diagrams are made from the Wheatstone bridge used for demonstrating a broken cable at the Polytechnic of London by Mr. Becker. The bridge is constructed eight feet long and two feet eight inches wide; the lozenge-shaped brass plates are one and one-half inches wide. There are four brakes with binding-screws, and, by using bobbins upon which the B. A. unit of German-silver wire was wound, the students were made to understand that each bobbin represented a mile of pure copper wire, No. 16.

resistance coils, A', A, and the respective currents might pass direct to the key, K (where contact is made or broken), and through that to the other pole of the battery; but the currents are partially arrested by the equal resistance coils, B', B, and a portion of the currents is forced into or divided into the galvanometer, $G\ N$.

The use of the coils, or any other resisting matter, on the other side of the galvanometer is to force, or rather gently to impel, a part of the current into the galvanometer; because if this were not done the deflection would be so small that it might be barely perceptible.

Let us say, for the sake of discussion, that 2 parts pass to the galvanometer from Q and 2 parts from S; such currents, coming in opposite directions, must oppose each other's progress through the galvanometer, and therefore the needle of the latter does not move.

We have only now to suppose that $4 + 2 = 6$ proceed from Q to

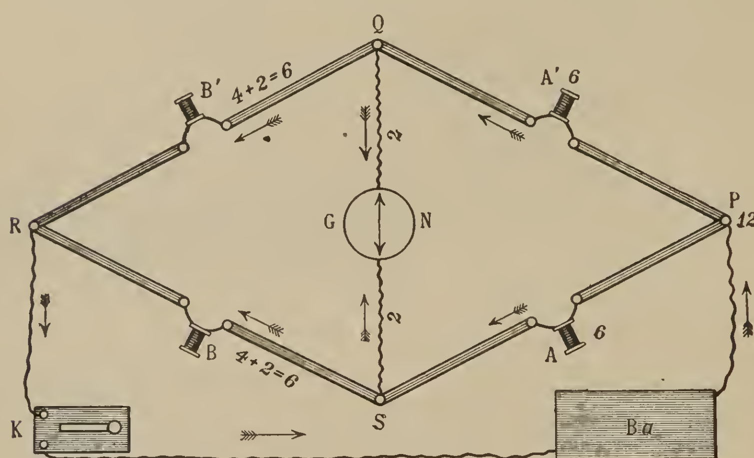


FIG. 13.

R, and $4 + 2 = 6$ by S to R; the two added together make 12, the original quantity started with, which proceeds through the key and connecting wire to the other pole of the battery, Ba.

The second diagram consists of two parts, viz., Part I and Part II, and it is recommended that the latter be traced on tracing-paper and placed upon the former. The current again is represented by 12 parts. The resistance of the coil at A', Part I, being less than A, Part II, the greater part of the current—say, 8 A' parts—goes through the former, and 4 A through the latter, consisting of a piece of copper wire and a resistance coil; therefore, returning to Part I, the current going by A' through Q to $G\ N$, the galvanometer needle, forms, at the point Q, a greater partial current (say, 3 parts) than the current going by A, Part II, which divides at S, and is represented by, say, $1\frac{1}{2}$ parts; therefore, the current that deflects the galvanometer is the greater going by Q, Part I, and marked 3;

consequently, it amounts in imagination to a struggle between the current going by Q, Part I, represented by 3 parts, and the current going by S, Part II, or $1\frac{1}{2}$ parts. The issue cannot be doubtful; the greater

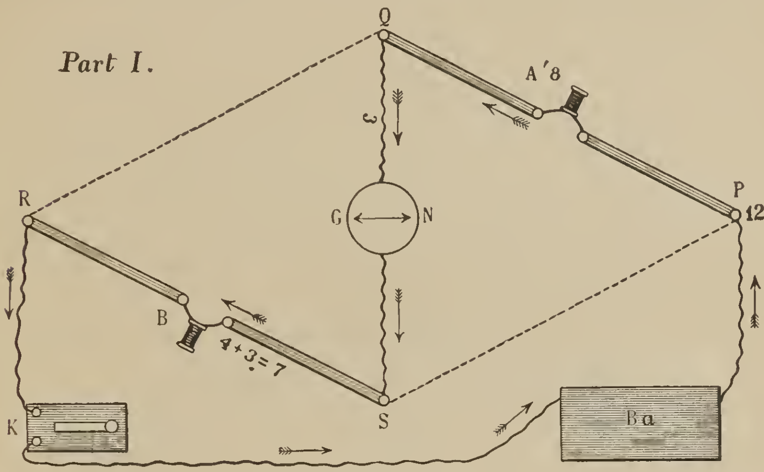


FIG. 14.

current, 3, overcomes the lesser, $1\frac{1}{2}$. In Part I, $4 + 3 = 7$ go by B, and in Part II 5 go by B'; and if the two are added together they again make the 12 parts, which, as before, travel through the key and connecting wire to the other pole of the battery, *Ba*.

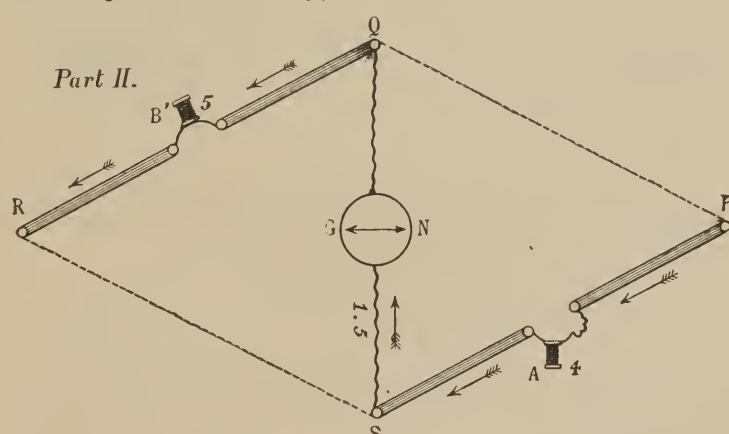


FIG. 15.

The next diagram (Fig. 16) explains the use of the bridge for comparing the conductivity or resistance of wires of different metals or different lengths of same wire. The lower part (A to B) of the bridge marked in dotted lines is not required, its place being filled by a long German-silver wire stretched from P to R, and provided with a scale

divided, say, into 20 parts; on this the galvanometer screws, the other screw of the galvanometer being connected with Q.

In this case we are to suppose it is being used to ascertain the relative lengths of wire of the same metal, diameter, and conductivity. The clip, S, has been moved from the centre, C, to No. 13.334 on the scale painted below the wire, P to R. The clip has been moved to 13 334, or until the galvanometer is at rest; this quantity, 13.334, is double that of R to S, therefore the resistance at B' is shown to be half the resistance at A', because A' has two coils or two miles of wire, and B' one mile; so that it is shown, without any previous knowledge of the absolute length of the two coils at A' (the wire under examination)., that it is double the length of the known quantity, one mile at B', because the scale from R

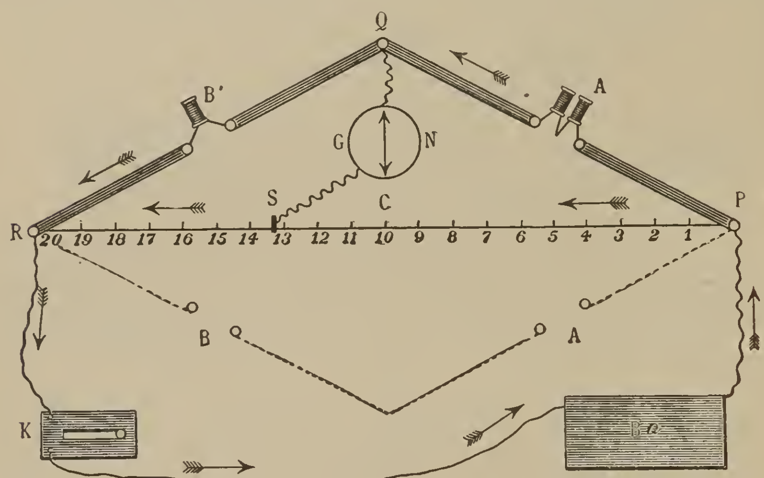


FIG. 16.

to S is 6.666, and that from P to S 13.334, and if one is added to the other they make up the whole scale of 20.

THE GALVANOMETER.

It is of the highest importance that the electro-therapist shall be able, during the course of an electrical *séance*, to see at a glance in what direction the currents are passing, and measure their strength. For this purpose a galvanometer of some form or make is necessary.

One of its most important functions is the testing and measurement of the resistance of line wires, instruments, coils, batteries, and insulation, and for many other similar purposes.

Its operation depends upon the action of the two forces—electricity and magnetism—and, though galvanometers are made in many forms and are used in several different ways, they are all based on the fundamental fact that a magnetic needle is deflected or turned aside from its

natural position by the passage of a current of electricity in a conductor placed parallel to it.

When a steel needle is magnetized and delicately pivoted at its centre, so that it is free to move horizontally, every one knows that it will set itself north and south, a common example being the ordinary compass-needle.

This action of the needle is due to the influence of the earth, which is itself an enormously large and strong magnet. All magnets attract the opposite poles and repel the similar poles of other magnets. For instance, the north pole of the earth attracts the south pole of the magnetic needle, causing the needle to point north and south as it does.

Among those who had studied most deeply the phenomena of galvanic electricity was Hans Christian Oersted,—a Danish physicist and professor of physics in the University of Copenhagen,—of whom we have already spoken in our " historical sketch." Oersted's researches led him to suspect the identity of magnetism with electricity, but for a long time no means of experimentally proving the fact revealed itself. The expedient had been tried, but without results, of placing the two poles of a battery, as highly charged as possible, in a parallel line with the poles of a magnetic needle. In one of the reports of the Smithsonian Institute the story of his discovery is thus graphically told : " Fortune, it might be said, ceased to be blind at the moment when to Oersted was allotted the privilege of first divining that it was not electricity in repose accumulated at the two poles of a charged battery, but electricity in movement along the conductors by which one of the poles is discharged into the other, which would exert an action on the magnetic needle. While thinking of this—it was during the animation of a lecture before the assembled pupils—Oersted announced to them what he was about to try. He took a magnetic needle, placed it near the electric battery, waited till the needle had arrived at a state of rest; then, seizing the conjunctive wire traversed by the current of the battery, he placed it above the magnetic needle, carefully avoiding any manner of collision. The needle was at once in motion. The question was solved. Oersted had crowned, by a great discovery, the labors of his whole precious life."

On July 21, 1820, the discovery was announced that a galvanic current passing through a wire placed horizontally above and parallel to an ordinary compass-needle, would cause that needle to sway on its axis to the east or west, according to the direction of the current through the wire. Oersted's discovery may be said to have pointed the way to the great applications of electricity to human use, for it showed that energy in the form of electricity could be converted into energy in the form of mechanical motion.

What are the Underlying Principles of the Galvanometer?—The

amount of deflection of a magnetic needle depends, to a certain extent, upon the strength of the cureent.[1]

"If the electric wire is above the needle, and the direction of the current is from north to south, the needle will tend to point eastwardly. Leaving the wire still above the needle, and changing the direction of the current so that now it flows from south to north, we find that the north end of the needle now deflects in a western direction. If the wire is changed to a position under the needle, it is found that all the motions are reversed; for passing a current from south to north the needle has an eastward inclination.

"It should be here explained that when we speak of the deflection of a needle the north end of the needle is uniformly the one referred to, the south end, of course, moving in an opposite direction.

"It can be readily understood why these movements should occur, and their reason. We have already indicated the cause of the natural inclination of the magnetized needle to place itself in a position pointing north and south to be the attraction of a much stronger magnet—the earth—and we may easily believe that an unseen force which causes the needle to point away from the north must also be of a magnetic character; and so it proves to be, and the reason of the deflection is as follows:—

"A wire carrying electricity becomes practically itself a magnet; that is, a straight current produces in a wire a magnetic field. This any one may easily prove for himself by passing an electric current through a wire of iron, copper, brass, or any other metal, and permitting the wire to dip into a heap of iron-filings. The filings will instantly cling to the wire and all around it, just as if it were a natural magnet. The electric wire having thus virtually been transformed into a magnet, when placed beside the magnetic needle, interferes with the attraction of the earth and pulls the magnetic needle to one side.

"The case is simply a very weak but very near magnet—*i.e.*, the current-carrying wire acting on a poised magnetic needle—in opposition to a very strong but very distant magnetic pole, the north pole of the earth; and thus the needle, being acted upon by both oppositely, takes up a half-way position,—as it were, 'on the fence.'

"The earth's magnetism tends to make the needle point north and south; the electric current acting on the needle tends to make it assume a position pointing east and west. The resultant force will, of course, be between the two, and will depend on their relative strength. If the current is very strong the needle will turn a long way around, but never farther than to a complete right angle."

Up to this point the effect of one parallel wire only had been considered. But if a greater deflection be required, and the battery power cannot conveniently be increased, what is to be done?

If the battery power cannot be increased in this manner, we can

[1] Electrical Measurements and the Galvanometer, T. D. Lockwood, 1890

increase its power of acting upon the needle by using a parallel wire on both sides of the needle; for, if the conducting wire is carried first over the needle from north to south and then back from south to north under the needle, the effect will be doubled. If the wire, instead of making only one such convolution round the needle, were to make two, the force would again be doubled; and if several combinations are wound around the needle, the force would be increased nearly in proportion to the number of convolutions.

If the convolutions are greatly multiplied so as to form a coil, the force is enormously increased, and we have what the first constructor of the galvanometer called a "*multiplier*." All galvanometers, therefore, consist of a coil of insulated wire and a magnetic needle delicately suspended in such a position as to be easily deflected by the passage of a current of electricity through the coil. These, with the addition of a dial-plate, graduated so that the movements of the needle may be interpreted, are the only absolute essential features of the instrument.

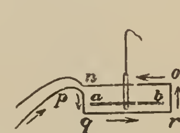


FIG. 17.

The galvanometer was one of the earliest results of Oersted's discovery; it was, indeed, in the same year (1820) that the first galvanometer was invented by Prof. Johann S. C. Schweiger, of Halle. He gave it the name of "multiplicator," the object of which, as aforesaid, was to multiply the electro-magnetic action of the current. This instrument is actually so sensitive that it serves to detect the weakest electric currents. All parts of the current traversing the elongated parallelogram, $p\ q\ r\ o\ n$ (Fig. 17), in the direction of the arrows, act in a similar manner upon the needle, $a\ b$, which rotates in a horizontal plane. If a be the south end and b the north end, the current will show a tendency at all points to turn the needle in such a manner that b shall project beyond the plan of the figure, while a will retreat behind it. The lower portion of the wire, therefore, supports the action of the upper in the same manner as does the current of the same force, moving in the same direction around the needle in the portions $p\ q$ and $r\ o$. A second current of the same force, moving in the same direction around the needle, will produce as great an effect as the first; so it will be with a third, a fourth, etc. A wire, therefore, wound around a needle in one hundred convolutions, all of which are traversed by the same current, must produce an action of one hundred times greater intensity than one of a single convolution; the current must not, however, be propagated later-

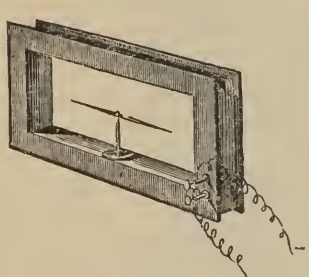


FIG. 18.—SCHWEIGER'S MULTIPLIER.

ally from one winding to the other, but must traverse the wire throughout its whole length, being carried actually around the needle.

The Schweiger multiplier is represented on preceding page. The difference between the rectangular and circular form is merely a matter of detail. Although the ordinary galvanometer, constructed as stated, is very well adapted to detect the presence or to indicate the direction of a current for some simple measurements, especially for those in which the deflection is not greater than fifteen or twenty degrees, it is not to be depended upon for any testing in which a greater deflection is produced, for the following reason, that when a needle is deflected it is not in the same position in its coil as when at zero; the greater the deflection, the farther is the needle removed from the position where its coil most powerfully influences it, and the nearer the needle approaches the right angle, at which point the coil has no influence on it at all, the weaker does the action of the current become.

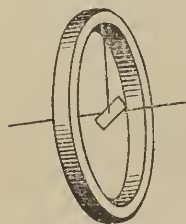


FIG. 19.

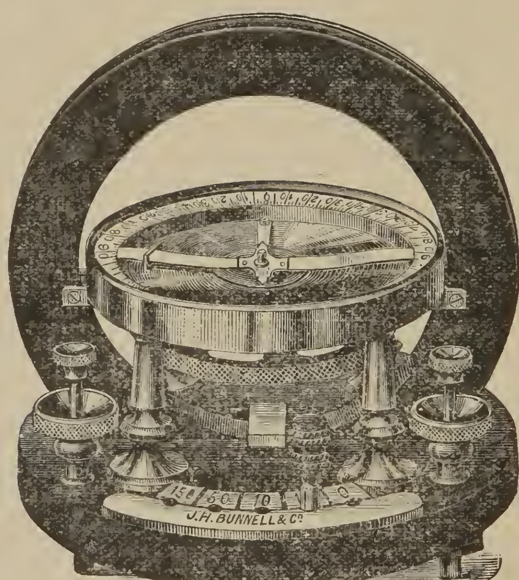


FIG. 20.—TANGENT GALVANOMETER.

In order to overcome this difficulty, and for other mathematical reasons, galvanometers have been invented in which the tangent, or line of the angle of deflection, is proportional to the strength of current measured. These are called *tangent*, or *sine*, galvanometers.

The Tangent Galvanometer.—The tangent galvanometer consists, broadly speaking, of a ring having a groove on its edge filled with in-

sulated wire, and provided with a needle, which must not be longer than one-sixth of the diameter of the ring, hung or pivoted precisely in its centre, as shown in Fig 19.

This instrument, as shown in Fig. 20, is mounted on a hard-rubber base, seven and three-eighths inches in diameter, provided with leveling screws and anchoring points. The galvanometer consists of a magnetized needle seven-eighths of an inch in length, suspended at the centre of a rubber ring, six inches in diameter, containing the coils. The coils are five in number, of the resistances 0, 1, 10, 50, and 150 ohms. The first is a stout copper band of inappreciable resistance; the others are of different-sized copper wires, carefully insulated. Five terminals are provided, the plug holes of which are marked, respectively, 0, 1, 10,

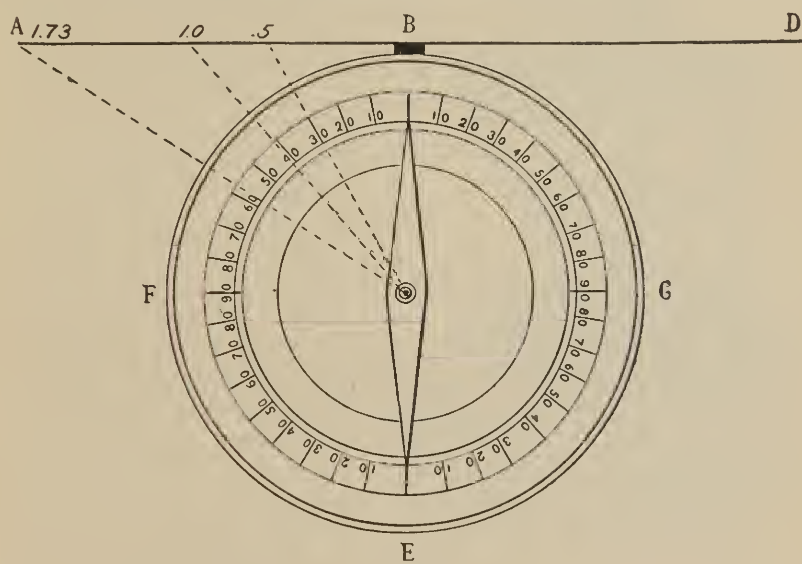


Fig. 21.

50, and 150. The ends of the coils are so arranged that the plug inserted at the terminal marked 150 puts in circuit all the coils at the terminal marked 50, except the 150-ohm coil; and so on, till at the zero terminal only the copper band is in circuit.

Fixed to the needle, which is balanced on jewel and point, is an aluminium pointer at right angles, extending across a five-inch dial immediately beneath. On one side the dial is divided into degrees; on the other it is graduated, the figures of the scale corresponding to the tangent of the angles of deflection.

For the benefit of the non-mathematical experimenter we may explain that a tangent is a line drawn at right angles to one of the diameters of any circle and touching the circumference, as in Fig. 21. *A* to *D* is a tangent to the circle *B*, *C*, *E*, and *F*.

In the case of the tangent galvanometer the dial of the instrument is the given circle, and the zero point is the point at which the tangent touches the circle. The tangent is therefore an imaginary line, which must be parallel to that diameter which connects the degree of 90 on one side to the same degree on the other side, and at right angles to the diameter or line connecting the two zero points. Let us suppose that the circle is the dial of a galvanometer marked off into degrees, and that the needle, by a given current, is deflected to 27 degrees; double the strength will not double the deflection, making 54 degrees, but will produce a deflection which, carried out, will show double the distance measured on the tangent scale, and that deflection will be 45 degrees. In mathematical tables the tangent of 45 degrees is 1. Therefore, that of 27 degrees is .5, or thereabouts; 64 degrees, 3; and 76 degrees, 4; all the intermediate degrees, of course, producing proportional fractions on the tangent scale.

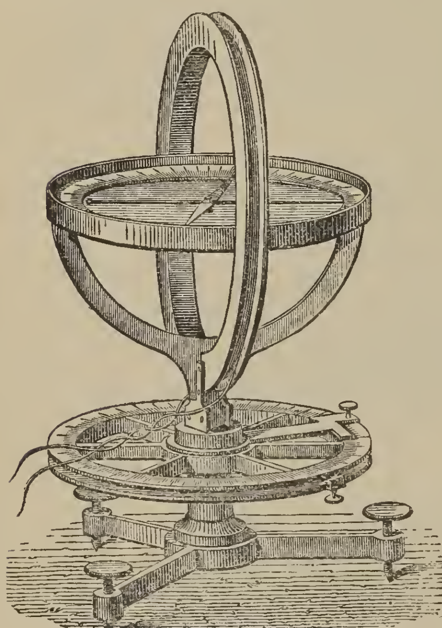


FIG. 22.—SINE GALVANOMETER.

Thus, we see that a current producing a deflection of 76 degrees on a tangent galvanometer is just four times as strong as a current producing a deflection of 45 degrees on the same galvanometer. If a tangent galvanometer is graduated to degrees only when it is used to obtain correct results, we must reduce the degrees to tangents by means of a table of tangents.

A tangent and sine table can be found in many of the first-class works,—as in Lockwood's "Electric Measurement."

The Sine Galvanometer.—The sine galvanometer, which was invented by Pauillet, is one in which the coils are made movable, so as to be capable of revolving on the axis around which the needle turns. The needle is pivoted, or suspended horizontally. A scale graduated with degrees is attached to the coils, and a pointer fixed in the base so that the angle through which the coils are turned can be observed.

When the needle is deflected by a current passing through the coils the coils are turned by hand, following the needle in its deflection; as the coils are thus turned they, of course, maintain their power on the needle, and it accordingly diverges still more, but the angle it makes

with the coils becomes less and less, until at length a point is attained at which the needle remains parallel with the coils. When this point is reached, the influence of the earth's magnetism exactly balances the deflective force of the current. The strength of the current that produces the deflection will then be directly proportional to the sine angle through which the coils are turned. It is customary, as in the use of the tangent galvanometer, to read off the degree, and refer to a table of sines for the required sine.

The sine galvanometer is not so convenient for general use as the tangent galvanometer is, being most applicable to scientific experiments and for measuring and comparing weak currents.

The astatic galvanometer is one of the most sensitive instruments employed; so is the Thompson mirror galvanometer.

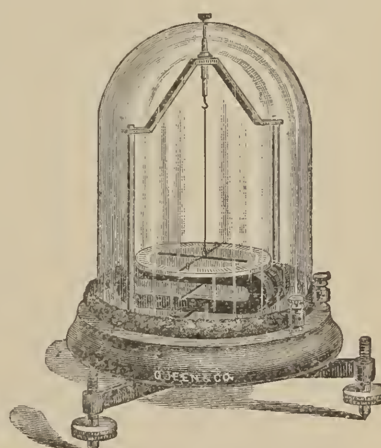


FIG. 23.—ASTATIC GALVANOMETER.

The differential galvanometer is one which has a needle poised or suspended like that of the tangent or sine galvanometers, but, unlike them, the needle is acted upon by two coils of equal length and resistance, insulated from one another with great care. These coils each surround the needle with an equal number of convolutions, which, in each wire, are equidistant from it.

When this galvanometer is used, one end of each coil with a wire leading to the pole of the battery is attached in such a way that the current flows in opposite directions through the two wires. Now, if the current in both coils is of the same strength, one tends to deflect the needle to the right and the other to the left, and the needle, being pulled with equal force in both directions, remains at rest. If, however, one current be made stronger than the other, the balance will be destroyed and the needle can be moved by the stronger current.

Unknown resistance can be measured with this galvanometer. This can be done in the following manner: We insert the resistance to be measured in the circuit of one of the coils. This, of course, weakens the current in that coil, and consequently its effect on the needle, which no longer remains balanced, but deflects to one side. If we now insert a rheostat in the other side and unplug the resistance until the needle again balances or comes to zero, we know that the current in each coil must again be equal, and, therefore, that the unknown resistance in the circuit of one coil must be exactly equal to the resistance unplugged from the rheostat.

A Dead-Beat Galvanometer.—So called on account of the readiness with which this galvanometer needle comes to rest, instead of swinging repeatedly to and fro.

There exists, besides these galvanometers for the commercial measurements of currents, a variety of forms. They are generally so constructed as to read off the ampères, volts, ohms, watts, etc., directly. They are called ampèremeters, wattmeters, etc. For their fuller description reference should be had to standard works on electrical measurements.

Having so far spoken of the cursory account of the theory of the galvanometer, and having described several of them, I will turn your attention to several galvanometers which possess certain features that, from the nature of the work they are called upon to do, are common to all galvanometers for medical purposes. We find the most important point connected therewith is, perhaps, the method of graduation. They are invariably of the fixed-coil, or "tangent" type,—that is to say, according to Steavenson and Jones ("Medical Electricity"), "the current indicated by any reading is proportional not to the angle of deflection, but to the trigonometrical tangent of that angle. Hence, it is necessary that the circle on which the position of the needle of the galvanometer is read must be graduated not uniformly, but so that the readings are angles whose tangents increase uniformly."

Calibration of a galvanometer is often called the graduation of a galvanometer. The galvanometer is graduated by dividing its circle into 360 degrees before the process begins.

The calibration of a galvanometer, for example, consists in the determination of the law which governs its different deflections and by which is obtained in ampères either the absolute or the relative currents required to produce such deflections. For various methods of calibration, see standard works on electrical testing, etc.

When a galvanometer is calibrated to read in milliampères it is called a "milliampèremeter," just as one calibrated to read in ampères is called an ammeter. The milliampèremeter is chosen as the standard for use in electro-therapeutics.

Many galvanometers are provided with a set of two or three resistance coils, which may be inserted in parallel with the galvanometer coils; they are usually of such values that they only allow one-tenth or one-hundredth or one-thousandth of the whole current to pass through the galvanometer.

The sensibility of a galvanometer may be varied in a very simple manner by the use of such coil, which is termed a *shunt.*[1] A shunt is a resistance coil, or coil of fine wire used to direct some definite portion of a current, taking it past a galvanometer instead of through its coils.

[1] Electricity and Magnetism. Fleeming Jenkin, F.R.S.S., L. and E., London. For the mathematical part relating to shunts, see works on physics.

Thus, let G, Fig. 24, represent the shunt. Let the resistance of the shunt be one-ninth that of the galvanometer, then of a total current from C to D nine parts go through the shunt and do not deflect the needle, while one part goes through the galvanometer; only one-tenth of the whole current is, therefore, effective in deflecting the needle, and the deflection, supposing a mirror galvanometer be used, is only one-tenth of what it would have been had no shunt been used. Similarly, by making the shunt equal in resistance to one-ninety-ninth of the galvanometric

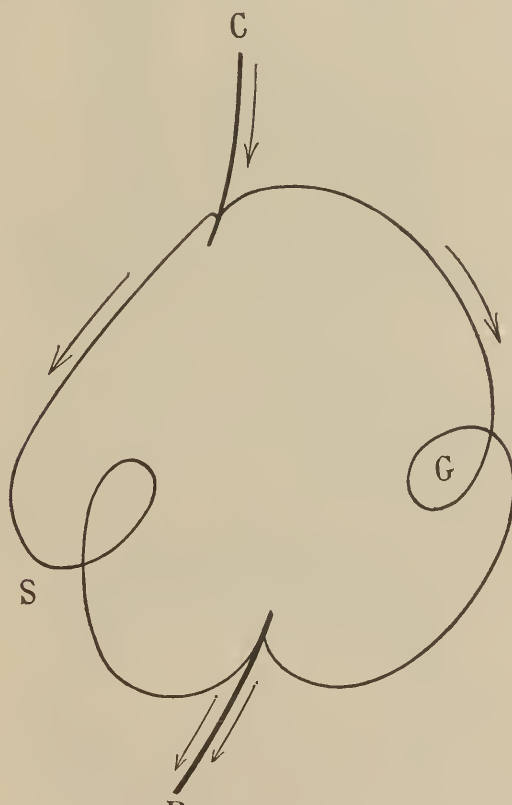


Fig. 24.

coil, we reduce the sensibility of the instrument to the one-one-hundredth part of its original sensibility.

All instruments used by electro-therapists are invariably calibrated and marked, as aforesaid, to read in milliampères, by all their manufacturers. These milliampèremeters are made up into two different styles, as the vertical and horizontal. Fig. 25 is a horizontal one designed for physicians; it is direct reading, and thus a means of obtaining quick, accurate, and reliable electrical measurements, such as

have hitherto been unattainable. No time is required for adjusting or waiting for the needle to come to rest, but readings can be taken immediately as soon as the circuit is closed. This instrument is accurately

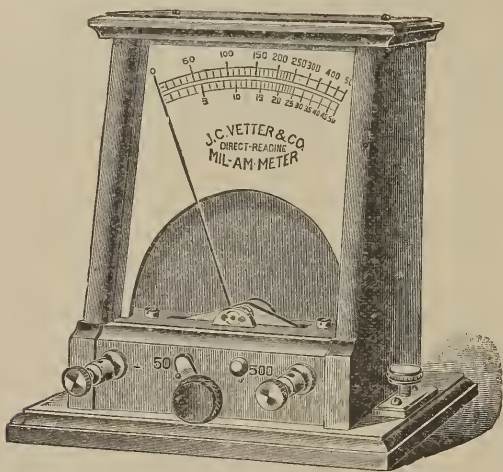


FIG. 25.—HORIZONTAL MIL-AM-METER.

calibrated and standardized. The staff is of hardened steel pivoted in ruby bearings with jeweled end-pieces ; it is provided with a switch, which, when placed on the 50 button, selects the lower or red scale on dial read-

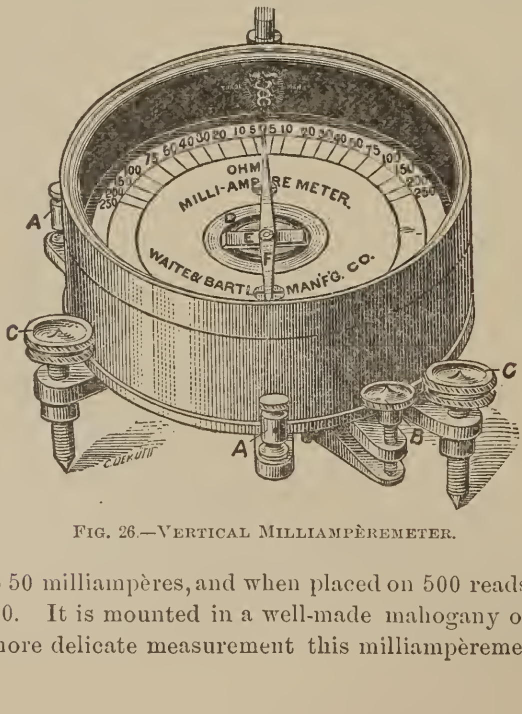


FIG. 26.—VERTICAL MILLIAMPÈREMETER.

ing from 0 to 50 milliampères, and when placed on 500 reads black or top scale, 0 to 500. It is mounted in a well-made mahogany or antique-oak case. For more delicate measurement this milliampèremeter is divided

on a lower scale, from 0 to 10 milliampères, and again subdivided in such a manner that one-tenth of a milliampère can readily be read off.

Among the vertical milliampèremeters the one made by Waite & Bartlett is the best, for many reasons.

The coils are made of two semicircles, so that practically you have a horseshoe solenoid for affecting the needle. The resistance of these coils combined averages fifteen-hundredths of an ohm. The magnet is made in horseshoe form, the poles of which swing in a circular groove in a copper block; the effect of this is to dampen the magnet, and so make it dead-beat. The magnet is supported on a jewel-point, which is so arranged that it can be lifted from the needle-point while being transported, which prevents injury to point of needle and jewel. All of the milliampèremeters made by the Waite & Bartlett Manufacturing Company are calibrated individually, and, for this reason, are uniform and

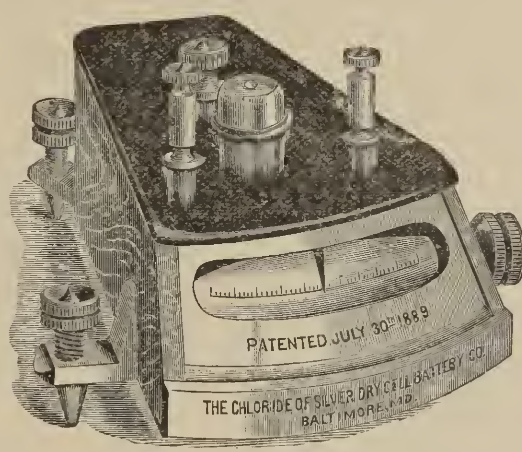


FIG. 27.—MIL-AM-METER.

correct. The instruments are in an all-brass case, finished in the same style as a microscope.

Another very excellent vertical mil-am meter is the one manufactured by the Chloride-of-Silver Dry-Cell Battery Company, of Baltimore. These meters have qualities which must also prove themselves satisfactory to the therapist. The following claims are made for them :—

1. An absolute electrical meter should be *accurate*. The best conditions for this accuracy are the use of short magnetic needles in connection with a long pointer. In this meter the magnetic needles are less than one inch long, while the pointer—made of aluminium for lightness—is four inches long, thus securing an extended indication on the scale for a very slight movement of the needles.

2. Such a meter should be as free as possible from variations due to changes of time and surroundings. This double object is accomplished

by employing a horizontal movement and an astatic system of magnetic needles, controlled by a fixed magnet, which is permanently under the influence of an armature or keeper, for preserving a uniform degree of magnetism. Such a system of needles is free from the influence of the earth's magnetism, and is the most constant in its action.

3. Friction must be entirely absent. This is accomplished by the use of a perfectly-pointed steel pivot working in a concave jewel, as in the best absolute galvanometers known to electricity.

4. The free parts of the instrument must be provided against accidental displacement. This is attained by a simple detail of mechanism, so that the magnetic needles cannot get off the pivot, even if shaken wrong-side-up or otherwise roughly used. A simple-locking device also provides for lifting the needles from the pivot and holding them fixed for transportation.

5. A physician's milliampèremeter should be readable from either a sitting or standing position. In this meter the face is at the front, at an angle which satisfactorily meets these points.

6. The perfect meter should have a wide range of measurement. This has been obtained in this meter by an entirely new arrangement. Three independent reading-scales are stamped at equal distances apart on the three faces of a celluloid roller. One of these scales is marked in 5 milliampères, divided into halves. The second scale is divided into 25 milliampères, and the third scale reads up to 250 milliampères. This meter reads directly.

Besides these described there are others, as the Weston standard direct-reading mil-am-meter, which has a scale of 0 to 500, 0 to 10. The instrument is readable from 0 to 10 milliampères by one-tenth; 0 to 500 by 5 milliampères. This instrument will operate in any position, and is not influenced by magnetism.

The McIntosh milliampèremeter has many advocates, and is certainly a very fine and accurate instrument. The D'Arsonval and the Gaiffe are also well known, besides many other American and foreign makes.

The Galvanometer Battery Gauge.—This is a new instrument entirely, and differs essentially in its construction and aim from all other galvanometers. This gauge is constructed and calibrated to furnish a reliable standard for the practical measurements of current-strength of from 1 to 5 cells of ordinary batteries. A good Leclanché cell will indicate about 9 degrees; Burnley dry battery, 14 degrees; Lockwood American District (blue vitriol), 6 degrees; Crowfoot Western Union form, 8 degrees.

These gauges, being calibrated to a single standard, furnish an accurate instrument for battery comparisons or condition tests. The gauge being a true galvanometer, without springs or magnetic devices, its indication for a given force is always the same. It can be used standing upright on table or desk, or suspended by its chain and ring,

which brings the needle to zero when no current is passing the instrument. Also, on account of their normal positions being upright, these gauges can be advantageously used as permanent circuit-indicators. The action of the needle is "dead-beat." It moves to and remains, without oscillation, at whatever indication the current calls for.

Two silk-covered conducting cords are attached to each gauge. These cords are provided with new and improved tips, made so as to enter any binding-post, and to be held by the binding-screw in the usual way, or, being square, can be firmly held by the English form of binding-post. These tips have a spring-clamp, by which they can firmly grip

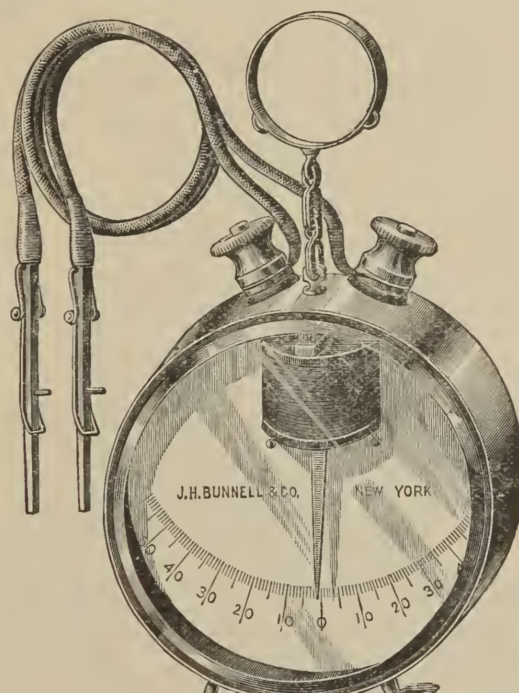


FIG. 28.—THE GALVANOMETER BATTERY POCKET-GAUGE.

naked wire (up to No. 16) at any exposed point, and thus also be able to detect a flow in circuits of fire-alarms, burglar-alarms, etc. Such a gauge must become serviceable to medical men to detect the power of their batteries, which is highly essential during or before treatment of any case.

RHEOSTATS.

The name rheostat was originally given by Wheatstone to an instrument which he devised for the purpose of varying at will the amount of resistance in a circuit.

The modern rheostat is a box containing a number of spools filled

with insulated wire; the resistance of the wire on each spool being equal to some multiple or submultiple of the ohm, the unit of resistance. The several coils (Fig. 29) and a complete box-rheostat (Fig. 30) are shown below.

The different coils may be of any required resistance, and may be

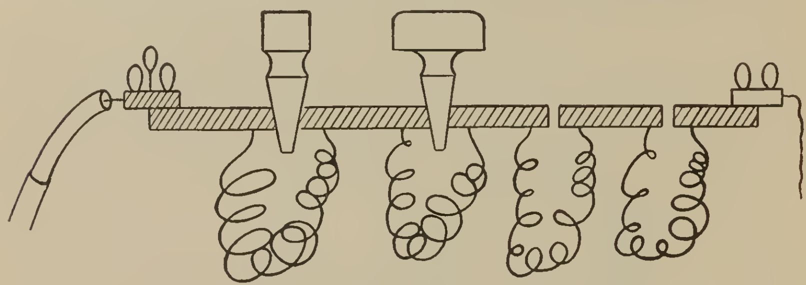


FIG. 29.—COILS.

varied indefinitely. They are usually made to increase consecutively, as, for example, 1, 2, 5, 10, 20, 50, 100, 500 ohms, and so on.

If all the plugs are in their places, there is practically no resistance between the terminal binding-screws; but if any of the plugs be taken out, the coil of that section is brought into the circuit. It follows, then, that by withdrawing any or all of the plugs we can introduce less or more resistance.

Numbers representing the various resistances of the coils are usually

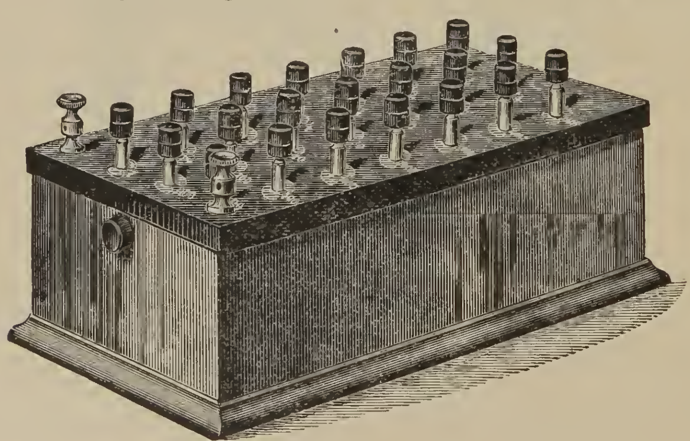


FIG. 30.—STANDARD BOX-RHEOSTAT.

placed opposite the holes, and by adding together the numbers unplugged we ascertain the total resistance inserted.

The wire used in resistance coils is generally made of German silver, because the resistance of that alloy changes very little with variations of temperature; it is insulated with silk, and always wound double, as

shown, so as to neutralize any inductive action of the convolutions on each other, and also to prevent the coils from affecting galvanometers near them; when so arranged, the current flows at the same time in two opposite directions round the spool, effectually preventing any inductive troubles.

It is usual to so arrange the different resistances that, by properly combining them, any value, from a fraction of an ohm to 10,000 ohms, can be obtained.

Those rheostats which are now mostly used by medical men are of the wire, the water, and the carbon order. I will describe and illustrate the three different kinds. They all have their merit and their demerit.

The Vetter Carbon Rheostat.—The principle adopted in the construction of this rheostat is the effect of variation in resistance, which

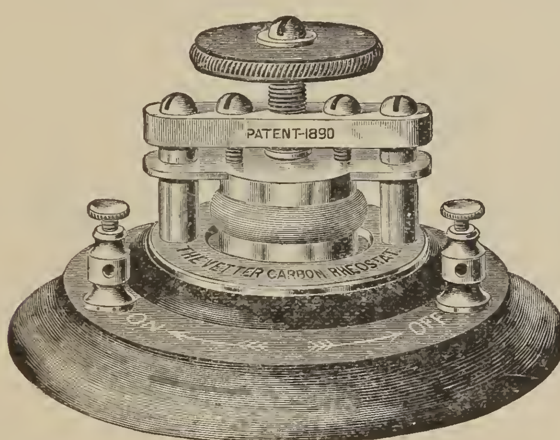


FIG. 31.

takes place in carbon with a change in pressure. A quantity of specially-prepared carbon, in a finely-divided state, is placed in a small rubber pouch or cylinder, which is inclosed by two metal plates, to which the two sides of the circuit are connected. The lower plate is fixed to the base of the instrument, and the other, traveling in upright guides, can be depressed, by means of a screw with a fine thread, so as to compress the carbon in the rubber cylinder. In this way the current passing can be adjusted with the greatest nicety. The variation in the resistance of the rheostat follows the movements of the screw through very wide limits, thus controlling from off or no current to the full capacity of the battery.

This instrument is far in advance of any rheostat, switch-board, or cell-selector. It imposes equal work upon all the cells of a battery, maintaining the current throughout the series of uniform and equal strength. There is also a saving of a mass of complicated wires from the cells, as only the two terminal wires from the battery are necessary.

The absence of liquid in glass and the many advantageous features it possesses make it the most desirable instrument for the purpose.

The Water Rheostat.—This is another resistance apparatus much lauded over by some medical men. There are several of them in the market. The latest of them is the Bailey current-controller.

This instrument, briefly described, consists of two triangular-shaped carbon plates, each carrying a conical sponge at one of its angles, and mounted over a glass vessel containing water. By means of a worm gear operated by a thumb-knob the sponge-tips are gradually immersed into the water and toward each other. It is so arranged that by turning a thumb-screw the left-hand plate may be unlocked from the gear and immersed as far into the water as desired, and then the other plate gradually moved toward it. This, the last method, gives a more gradual increase of current, as one plate is moved in place of the two. Each plate

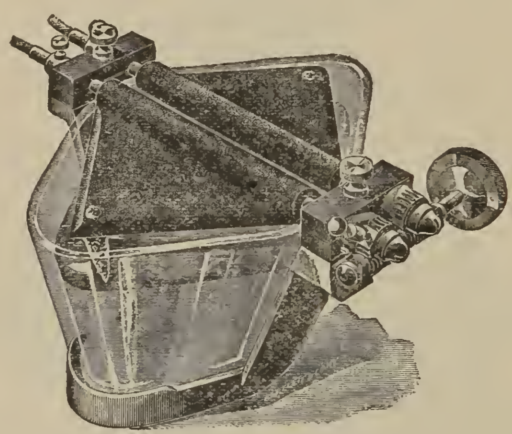


FIG. 32.—BAILEY CURRENT-CONTROLLER.

measures three and one-half inches by three and one-half inches by four inches; the entire device is over all seven inches long, seven inches wide, four and one-half inches high, and weighs two pounds. This current-controller, or rheostat, will give a current at the outset more feeble than any other instrument of this kind or character, and will increase the current without variation or fluctuation. When the plates are raised out of the water they are separated fully three-sixteenths of an inch; thus it is impossible for the escape of the current by means of water adhering between the plates, or by moisture or condensation.

The principal advantages of the water rheostat over the wire-coil rheostat, are as follow: Its simplicity, avoiding the complicated wiring incidental to wire rheostats; greatest certainty of preventing shocks, and its low value.

The ordinary water rheostat is known to most practitioners. It consists of a glass cylinder, water-tight, and filled with water or some

saline solution. It terminates below in a metal foot and binding-screw, and a metallic rod, moving stiffly, passes in from above through a collar, and this carries the other binding-screw. When the rod is pushed quite down it touches the base of the tube, and the circuit is completed through the metallic contact; when it is raised the current must pass through the badly-conducting fluid.

A good rheostat is the McIntosh hydro-platinum. The figured one in the cut is devised for the special object of rendering it possible of increasing or decreasing the strength of the current in absolute gradual gradations, from zero to the full current-strength and back again.

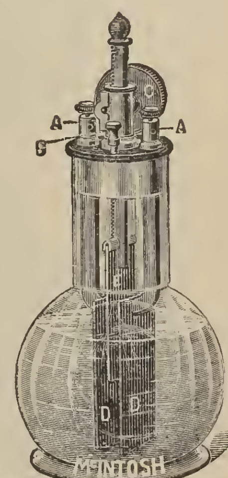


Fig. 33.

Between two small, thin sheets of platinum (*D D*) suspended in water with suitable attachments (*A A*) for one pole of the battery is suspended a third piece of platinum (*E*) with pointed end, which can be lowered or elevated gradually in the water between the other two sheets (*D D*), by means of a delicate ratchet combination (*B C*) above. This plate is connected with the other pole of the battery by one of the binding-posts (*A*). When plate *E* is elevated so that its pointed lower end is out of the water no current can pass the instrument, but as it is gradually lowered into the water the resistance becomes gradually less and less, until the desired current-strength is reached, or until the full capacity of the battery is obtained. Thus, by elevating or lowering this central sheet, a current of great strength can be perfectly controlled in gradual gradations, no shock being possible.

There are other kinds of rheostats made by the various surgical-instrument makers throughout most of our large cities. Those made by the Waite & Bartlett Manufacturig Company are perhaps the most widely known.[1] The Massey current-controller is a modification of the one known as the old Butler rheostat. The above-named firm have undertaken its modification, and to-day it looks as follows: The disc is made of slate with the cone-shaped surface roughened for retaining the graphite coating. The advantage of the slate is that it does not become soiled like the marble, and it always presents a neat appearance. The brush for moving over the resistance surface is made of spring-brass nickel plated, sufficiently broad to span the broadest part of the leaden portion, and the spring is split up in several places to insure perfect contact over the entire surface upon which it rests. One of the binding-posts attached to the wooden frame surrounding the disc connects with

[1] Augustin H. Goelet, M.D.: The Electro-Therapeutics of Gynæcology, vol. i, pp. 135, 136, 137.

the base of the leaded surface by means of the spring contact under the cap, and the other with the central pivot, to which the brush is attached by a lever; so that there is a break, so to speak, between the two when the brush stands at the point marked " start," removed from the coated surface. As the brush is moved upon the graphite the resistance is diminished the nearer it approaches the base. The graphite, which is really a good conductor of the current when spread out over a flat surface like this, offers a considerable resistance. In order to increase the resistance at the start, so as to permit the current to be turned on gradually from a battery of a great number of cells, it is necessary to make the graphite coating very much thinner there than elsewhere, and if too much has been put on it should be rubbed off until its presence is

FIG. 34.—THE MASSEY CURRENT-CONTROLLER.

scarcely perceptible at and near the starting-point. The only objectionable feature about the instrument is the perishable character of the graphite coating, which is being constantly rubbed off by the brush, but it is easily renewed by rubbing over the surface a carpenter's lead-pencil, or, in fact, an ordinary pencil; but the former having a larger surface of lead, the coating can be renewed more rapidly. It is possible with this rheostat to gradually remove the entire resistance by moving the brush up over the surface which has been covered with graphite, or, at least, the remaining resistance is so little as to be inappreciable.

The advantages of this rheostat are that it is flat, it occupies a very little space, it cannot be upset, and the connections are practically indestructible. It can be readily removed from the cabinet or table and transported for use elsewhere, though its size (the diameter being about seven or eight inches) makes it rather an awkward instrument for carrying conveniently in a bag.

Dr. A. H. Goelet, recognizing the fact that a smaller rheostat was needed for use with a portable battery at a patient's house,—one small enough to make a convenient package and readily carried in the pocket

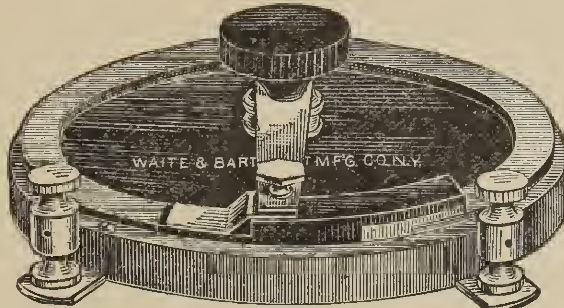


FIG. 35.—GOELET'S SLATE POCKET-RHEOSTAT FOR GALVANIC CURRENT.

from place to place,—was led to suggest the modification of this rheostat shown in the cut (Fig. 35), which is made for him by the Waite & Bartlett Manufacturing Company. It is a small disc of slate, only three inches in diameter, marbleized on the upper face and around the

FIG. 36.—WILLMS'S RHEOSTAT.

side. Around the margin of the upper face is a raised surface about one-quarter of an inch wide, not marbleized, but roughened for receiving a coating of graphite. The connections are made in the same

manner as in the Massey instrument. The contact of the lever with the graphite surface is made by a small wheel ground to fit the raised surface, which is made level, and in front of the wheel is placed a projecting spring-pressure foot, like that on a sewing-machine, to which is attached a piece of graphite for constantly renewing the coating. The object of the wheel is to make it move more smoothly and to avoid sudden jerks. The lever is turned by a thumb-screw fixed to the pivot passing through the centre of the disc, and can be manipulated with greater ease than the other instrument. It can be used with forty or fifty cells as satisfactorily as the other instrument, but the same care must be observed not to have the graphite coating too heavy at the starting-point. Nearly all the resistance is cut out at the finish. A larger size is made, but it is not so convenient.

Fig. 36 represents a rheostat, recently introduced by the Chloride-of-Silver Dry-Cell Battery Company, of Baltimore, designed by Mr. Charles Willms, of the firm. The resisting material, consisting of common glue, graphite, and metal-filings (brass preferred), is placed on the under surface of the top plate; the graphite being really the resisting material, the brass-filings collecting the current and conducting it to the metal contact-points leading to the surface, where the turning-crank forms a connection with them. This is considered a very finely-constructed and practical instrument. Most of the portable batteries have been so designed that a rheostat is placed on the mechanism in such a way that is most practical.

Introductory Remarks on Primary Batteries.

Battery Defined.—An electric battery, or cell, as a single element is called, is a device for the conversion of the potential energy of chemical separation into the energy of an electric current. Thus, the metal (zinc) and the sulphuric acid which acts chemically on it represent energy of chemical separation in the potential form. If now the zinc is placed alone in the acid, this energy of chemical separation is converted simply into heat, when the zinc displaces the hydrogen of the acid with the formation of zinc sulphate; but if the displacement of hydrogen by zinc is made to take place under certain less-simple conditions, then a part at least of the kinetic energy developed takes the form of the energy of an electric current. The arrangement of parts necessary to secure these conditions, which determine that the transformed energy shall be electrical, is called a battery, or voltaic cell.

The term "battery" is now to be found substituted in all works on electro-physics for the former historical one, "pile." It is stated by many that the word "pile" is, however, more correct.

The invention of the "electric pile," or battery, was Volta's great contribution to science, and dates from the year 1800. For many years it afforded the only means of generating electricity in considerable and

manageable quantities. Through its use many of the most remarkable discoveries were made. In various forms its practical applications have become so extensive and so common that it is probably the best known of electrical instruments. Its invention evidently came to Volta through his reflections upon the contact theory. Believing that electrical separation takes place when two dissimilar metals come in contact, he thought to magnify the effect of a single pair by increasing the number. Pairs of dissimilar metals of like dimensions were bound together by placing a thin, moist substance between consecutive pairs. Discs of metal, consisting of silver coins and pieces of zinc, and moistened paper, were used, and, when put together, the pile was formed as shown in the figure. When this was done, he found it no longer necessary to use so sensitive an electroscope as the legs of a frog to detect the electrification. He could himself feel the shock it produced by touching the opposite extremities of the pile, and immediately convinced himself of the identity of electricity with the so-called galvanism. All of the characteristic effects of electricity, as produced by friction upon glass, sulphur, and other substances, could be shown by the new instrument. It is interesting to note how nearly an Englishman—Professor Robinson—came to hitting upon the same invention. Volta modified the form of his apparatus by placing the two dissimilar metals in cups of water, and then joining them together by metallic conductors, thus putting his battery into a shape which it has retained, practically, to the present day.

FIG. 37.—COMPLETE PILE.

The pile shown in Fig. 37 exhibits the appearance of the instrument called the column-pile, which has to-day but an historical interest. It is a pile of discs, and the figure here represented is a *fac-simile* of the first cut published of the battery.[1]

First Idea of the Pile, or Battery.—If you immerse a thin plate of commercial zinc into diluted sulphuric acid a very lively action takes place; the zinc dissolves, and a considerable quantity of hydrogen is given off. It is, indeed, this process which is generally employed in the preparation of hydrogen-gas. But if, instead of ordinary zinc, pure zinc is used, the action takes place very slowly, and the bubbles of hydrogen remain attached to the plate of zinc and protect it from further action of the acid. If a wire or thin plate of platinum be now placed on the same, as soon as the two metals touch at one point the action becomes extremely energetic; the zinc dissolves and hydrogen is given off, but from the platinum, and no longer from the zinc.

As soon as the contact of the two metals ceases, all action upon the zinc and all giving off of hydrogen are suspended. This important experiment is to be credited to De la Rive. It throws much light upon all

[1] In my historical sketch I have described the origin of the voltaic cell, etc.

that follows. It is equally successful when you substitute for the platinum silver, copper, or even iron, and gives the same result when the metals have their points of contact either *in* the liquid or *out* of it.

De la Rive's experiment shows that if two metals were to have their point of contact *not in* the liquid, but *out* of it, as Fig. 38 represents, the chemical action still takes place in the liquid, as stated above. It also takes place if, instead of bringing the two plates of metal into direct contact, you put one upon the upper part of the tongue and the other upon the under part, when you will experience a slight sensation, like that of a feeble electric shock, and a peculiar taste will also be noticeable.

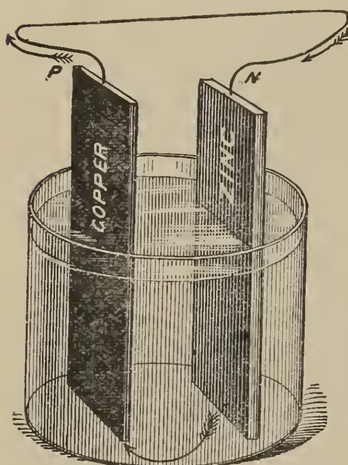


FIG. 38.

If you place upon the dry part of the zinc a strip of paper dipped in iodide of potassium, and then touch this dampened paper with the platinum, a blue spot is immediately produced, which shows that the iodide has been decomposed and the iodine set free. These experiments can also be made if you attach to the zinc and platinum two wires, and operate with the two loose ends. If you place one of these in the neighborhood of a freely-suspended magnetic needle, you will notice that the needle will deviate slightly from its north-south direction as soon as the contact is established between the two loose ends of the wires.

These observations prove that a singular phenomenon is established by the co-operation of the two wires, which is the cause of various actions,—physiological (upon the tongue), chemical (upon the iodide of potassium), magnetic (upon the needle).

FIG. 39.

The two metal plates immersed in the liquid are called *electrodes*, and the wires, long or short, which are attached to the electrodes, and which permit the transference to a distance of the effects produced by the battery, are called *rheophores*. The *rheophores* are generally short, and often end in a longer wire, to which the name of *conductor* is given.

The term "circuit" of the current is applied to the whole, formed by

the battery, the rheophores, and the solid or liquid conductor through which the current passes. Every apparatus which produces a current is a battery.

It is said that the circuit is *open* when at any point whatever the conductor be disconnected, as then all the effects of the current cease and the *current does not circulate.* The current is *closed* when the two parts of the conductor, which were separated, are brought into contact with each other and the current commences to flow.

It is said that a battery is in *short circuit* when the conductor connecting its poles has a null resistance; that is, when it is very short. It has thus come to be said that, *in the conductor, the current flows from the positive pole of the battery* (+plate of copper) to the negative pole (—plate of zinc); a transference of a peculiar fluid from one to the other of these points being thus implicitly admitted. Let us say, in passing, that this way of looking at things, after having been abandoned in science, shows a tendency toward re-acceptance, with a few changes; so that the conventional language, which had not been changed, finds itself again in accordance with the theoretical ideas admitted.

The cell formed of the electrodes of zinc and copper, immersed in sulphuric acid, is more particularly known under the name of volta. By changing the nature of the liquid and the electrodes, an indefinite number of cells which produce the same kind of energy can be obtained.

Chemical Reaction in the Simple Voltaic Cell.—If we suppose that the arrangement of metals and acid in the cell is as follows :—

Zn	|	H_2SO_4	|	H_2SO_4	|	Cu
Zinc.		Sulphuric acid.		Sulphuric acid.		Copper.

then the operation, which repeats itself over and over when the two metals are electrically connected, may be represented thus :—

$$\underbrace{Zn \quad | \quad H_2SO_4}\quad | \quad \underbrace{H_2SO_4 \quad | \quad Cu}$$

$$\longrightarrow$$

giving	$Zn\ SO_4$	|	H_2SO_4	|	H_2	|	Cu
	Zinc sulphate.		Sulphuric acid.		Hydrogen.		Copper.

The arrow represents the direction of the current through the cell. The zinc and hydrogen are both placed in the direction of the current, while the so-called "sulphion," or SO_4 part of the acid, is displaced in the other direction. All metals and hydrogen are electro-positive, and travel in an electrolyte with the positive current. Zinc sulphate is formed at the expense of zinc and sulphuric acid, and hydrogen-gas is set free at the copper plate. The simple chemical action taking place is the displacement of the hydrogen of the acid by zinc, forming zinc sulphate in place of hydrogen sulphate.

Inconstancy of the Simple Voltaic Cell.—It is found that all cells formed of two electrodes immersed in a liquid present an immense drawback; namely, their action decreases very rapidly from the beginning of the action. There are two causes for this decrease, of which the following is an analysis:—

The first is the loss of acid from the dilution. It can be easily understood that water acidulated in the proportion of 1 to 100 will act less energetically than water acidulated in the proportion of 1 to 10. This cause of the weakening of the battery is not felt until the expiration of a certain time, and it is easily avoided by adding, from time to time, acid to the dilution.

The second is the deposit of hydrogen upon the copper: If the current be interrupted during a length of time sufficient for the freeing of the hydrogen, it will be seen, as soon as the current is again closed, that the intensity assumes its original vigor. It suffices, indeed, to agitate the plate of copper, in order to cause the gas to free itself and to give to the current its initial intensity.

Constant batteries are those in which this second cause of weakening, called *polarization of the electrode*, is removed. The presence of hydrogen upon the electrode opposes a double resistance to the passage of the current, *a passive resistance* and *an active resistance;* it is the latter which is properly called *polarization of the electrode.* To depolarize the electrode is to provide against these resistances by suppressing the freeing of hydrogen.

In understanding perfectly everything pertaining to this question, therein will be found lies the whole difficulty concerning the improvement and perfecting of batteries.[1]

Various reasons have combined to designate the *positive electrode* as that one which represents the negative pole of the cell (zinc in Volta's battery), and the *negative electrode* as that one which represents the positive pole. (Copper or platinum in the cells which have occupied us to the present.)

One of these reasons has already been indicated, which is that the current enters the liquid of the battery by the negative pole and goes out by the positive; in other words, the *positive electrode* is that by which the electricity enters the cell.

In order to avoid difficulty in the choice of these denominations, one may, in speaking of them, call them the positive pole and the negative pole, when desirous of designating the corresponding electrodes according to the custom of practical men. But, if one wish to employ absolutely correct and scientific terms, great care should be taken in the application of them, in order to avoid the confusion consequent upon an awkward attempt at precision in language. Daniells gives in his work, "Introduction to Chemical Philosophy," another denomination, which

[1] Elementary Treatise on Electric Batteries. Alfred Niaudet, France.

ought to be employed more frequently than it is, because it presents the expression of a *fact*, and does not depend upon theoretical ideas. He calls the *generating electrode* that one which plays a part in the chemical action; while it is the zinc in the cell which we have considered. He designates as the *conducting electrode* that one which is not attacked, but which serves, however, to complete the cell. He adds that the first may also be called soluble electrode.

Battery Cells Joined in Intensity.—I have described the most simple cell that can be prepared, composed of two electrodes of copper and zinc immersed in acidulated water. The cell of Volta's column-battery does not differ essentially from this one; it is composed of two discs, one of copper and the other of zinc, separated by a circular piece of cloth, saturated with acidulated water.

Volta discovered, by delicate means, that the force of the current increased as the number of cells was augmented, and one of the most brilliant discoveries of modern times was the result. He thus showed that it was possible to add one source of electricity to another and to still a third, in such a manner as to obtain a multiple source of an indefinitely increasing power.

The Voltaic Battery and its Offsprings.—The batteries known as the column, Volta's Couronne de Tasses, Cruikshank's, Wollaston's, Spiral, Munke's, and Sand's,—all these differ only in their arrangement from that of Volta's; in every one we find the zinc, the copper, and the water acidulated with sulphuric acid.

It will be found that the chemical action is the same in nearly all batteries: dissolving of one metal, freeing of another. In all forms of Volta's battery hydrogen-gas is given off and the zinc will be dissolved without closing the circuit; that is, without the production of electricity by the battery. This is one of the greatest faults of this battery. It is consumed without doing any useful work. In most batteries the same difficulty is presented, with, however, a few exceptions.

General Remarks upon Batteries.

Ideas upon Electric Resistance.—The most simple way of showing the passage of electric currents in a conducting body is to bring its force to bear upon the magnetic needle. For instance, let us suppose that the conductor of a galvanometer, or of a simple detector, be inserted in the circuit of the current of a battery, and that the deflection of the needle be 25 degrees. Now, if the circuit be lengthened by the addition of a wire, the deflection will be seen to diminish to 15 degrees; and if the circuit be made still longer, the deflection of the needle will not exceed 10 degrees. We may thus draw the following conclusions:—

1. The intensity of the current is less in the second instance than in the first, and less in the third than in the second.

2. The influence of the additional wire being only passive, the reduc-

tion of the intensity of the current is due not to the decrease of the generating force, but to the increase of the resistance.

These experiments give a practical idea of the *resistance* that conducting bodies offer to the passage of currents; and they also demonstrate that the resistance of a conductor increases with its length. Very exact and oft-repeated measurements have proved that the resistance of a conductor is in proportion to its length, and in an inverse proportion to its sectional area. These laws can be found in all works upon physics.

General Remarks on Electro-motive Force and Resistance.

In all machines in motion is seen a power or cause of movement, and there are also resistive forces which tend more or less to slacken this movement or to stop it altogether. For instance, to illustrate this by a windmill. The large arms, under the pressure of the wind, cause the millstones which crush the grain to turn. In the working of the mill we see, first, a power,—the wind,—which produces the movement; then there is a resistance offered by the grinding; this resistance moderates the pace of the arms, and if the wind falls it stops them entirely. At first sight there are two mechanical elements apparent: the power, or cause of movement, or motive force; and the resistance, or work. A careful examination will show, however, that the resistance is complex; and that offered by useful work, as the grinding, should be distinguished from that which is the result of the friction of the different parts of the machine in motion and of certain secondary phenomena. All practical men know that a badly-oiled rubbing surface is sufficient to slacken the movement of a machine, and even to stop it; all know the importance of friction in the different parts of the machine, and of the stiffness of the belts and ropes. These inevitable causes of the slackening, which absorb a part of the motive power at the cost of the useful work desired, are called *passive resistance.* Every one knows that these resistances should be diminished as much as possible, although they cannot be totally suppressed.

Attention is here called to the fact that in many cases no useful work is done, and that there then remain only passive resistances. If the miller take away his millstones and still permit the mill to turn, it is evident that there remain only those passive resistances (friction and others) which are produced by the machinery remaining in motion. If all the machines of a large factory be disconnected from the motion-giving steam-engine and the engine continue to turn, there will only be present the motive force furnished by the engine itself and the passive resistances existing in the engine, in the shafts, and in the different agents of the transference of the movement which still remain in motion. If now the steam-engine run entirely alone, not being connected with any shaft or any piece of machinery outside of itself, we have not only the example of a system in which there are force and passive resistance, but also that

particular instance where these passive resistances are inherent to the force-giving machine and inseparable from the production of that force.

In a circuit through which an electric current flows the same influences are to be found; first, a force residing in the battery and called *electro-motive force;* next, the work; and, finally, the passive resistance. The work may be found in the movement of the clapper-spring of an electric bell; it may be in the movement of a telegraph instrument placed at a great distance from the battery; it may be in the movement of an electro-motor or an electro-magnetic machine which lifts a weight; it may be in a chemical decomposition, produced by the passage of a current in the production of heat, and consequently of light, in a voltaic arc, etc.

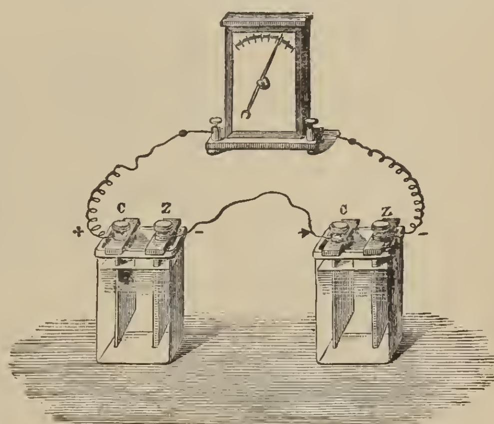


FIG. 40.

Passive resistances are the results of the circulation of the current in the different parts of the circuit. We have explained how their existence may be ascertained, and we have designated them by this one word, *resistance.* If the current produce no real work,—that is, if the circuit is composed solely of conductors, without the interposition of any apparatus which puts the current to any use,—the resistance is entirely passive. These considerations explain and justify the use of the word *resistance* applied to that property of reducing the intensity of the electric current which the conductors possess.

Electro-motive Force.—The cause which produces the electric current we have called electro-motive force. In order to give a clear idea upon this point force, we will adduce several experiments:—

If a battery cell be taken and the current which it produces caused to act upon a galvanometer, we shall then see that the needle is deflected; for instance, toward the right. If we change the communications of the battery with the galvanometer the direction of the needle's deflection will be altered, which shows that the direction of the current in the galvanometer has been changed,—if we now consider the first conditions: the needle deflected toward the right.

If now a second battery cell, differing in no way from the first, be taken and inserted in the circuit, and the negative pole of this second attached to the positive pole of the first, the two currents will flow in the same direction and join each other; we find that the intensity of the re-

sulting current is increased, and consequently the deflection of the needle is greater. In these conditions the two battery cells are *joined in intensity*, forming (Fig. 40) a battery of two cells. A battery of any number of cells could thus be formed, as stated before, but this is not the point upon which we wish to insist; we desire only to call the expression *battery cells joined in intensity*, and to determine the exact meaning.

Suppose that we now insert a second cell in the circuit of the first, but uniting the positive pole to the positive pole and the negative to the negative in such a manner as to have two poles of the same name ending at the galvanometer (Fig. 41).

Under these conditions the needle will remain stationary. This is not to be wondered at if it be remembered that the two cells tend to

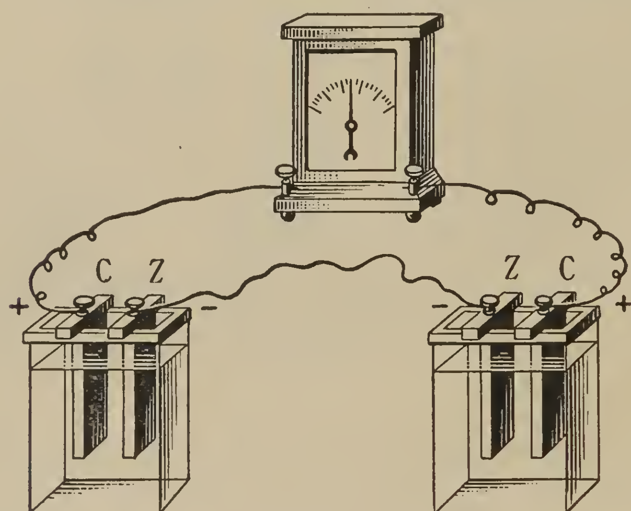


FIG. 41.

produce equal currents in opposite directions. The fact that these currents balance each other and that there is no movement either in one direction or the other is quite natural. It is said in this case that the two battery cells are opposed to each other, or are *joined in opposition.*

We have assumed, in the above, that the opposed cells were of equal dimensions. Each one acting alone would produce the same deflection of the needle, one toward the right and the other toward the left; both acting simultaneously in opposite directions cause no deflection whatever, which is quite natural and easily understood. Let us vary the experiment, and place in the same circuit (Fig. 42) a small voltaic cell, in opposition to a larger one of the same nature. We find that the needle will remain stationary, thus showing that there is no current. This result will appear strange to the uninitiated reader, and deserves to be dwelt upon. If made to act separately, they cause the needle to deflect, one

toward the right, the other toward the left. The current furnished by the larger one is more intense than the current produced by the smaller one, as the deflections of the needle show. But if these two cells be opposed to each other, the effect of one is counterbalanced by the effect of the other, and no current flows through the circuit. The conclusion of this experiment is that the electro-motive force of battery cells does not depend upon their dimensions. Experiments also show clearly that the electro-motive force of battery cells does not depend upon their dimensions, but upon the materials used in their composition.

Measurement of Electro-motive Forces.—It has been seen how, by means of an ordinary galvanometer, the electro-motive forces of different

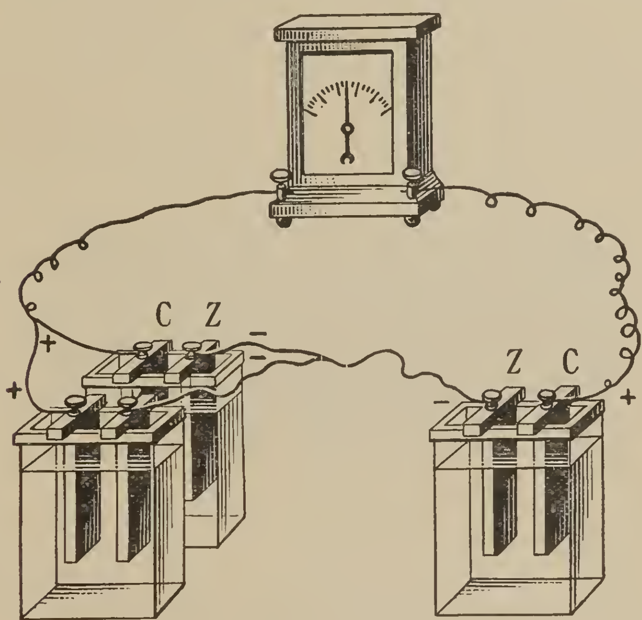


FIG. 42.

batteries may be compared. This method, just used and described, is called the *method of opposition*, because it consists in opposing equal or unequal forces. It can be easily understood how the electro-motive forces of different cells may thus be measured and tables of these forces made out. The electro-motive forces inserted between two dissimilar metals are altered by every change in their temperatures, but the connection between the change of temperatures and the change of electro-motive force has not been thoroughly investigated.

Electro-motive force may also be produced by electricity in motion, and by magnetism in ways which we cannot even describe, until the simpler phenomena of electricity in motion and of magnetism have been described; but it may be said generally that all causes which have the

power of altering the distribution of electricity can produce electromotive force or difference of potential. Every source of electricity must, as such, be able to produce a difference of potential; since no charge of electricity whatever can be made sensible without some difference of potentials, between the charged body and the earth, of neighboring conductors.

Internal Resistance of the Battery.—From the foregoing remarks it has been seen that the conductors outside of the battery offer a certain resistance to the electric movement, or, in other words, a resistance to passage of the current. Experiments show that the battery itself offers a resistance to the current it produces. From several of these observations it has also been concluded that batteries have an internal resistance in themselves, and that the resistance increases with the distance between the electrodes in the liquid, and diminishes when the immersed surfaces are increased.

If the battery be considered as a force-producing machine, it is not to be wondered at that it at the same time produces force and offers a resistance to that force. This condition is common to all machines; a part of the force they produce is absorbed by those passive resistances resulting from the action of the different parts of the machine. In a steam-engine, for instance, the friction of the steam in the pipes, the friction of the piston in the cylinder, etc., etc., cannot be avoided. This resistance of the battery has to be taken into account in nearly all cases, for the explanation of phenomena and for the calculation of results.

It can be seen that, of two batteries in which the electrodes are of unequal dimensions, the distance between them being equal in each, the one having the larger electrodes offers less resistance than the other; and it can be said, in general, that larger cells, when compared with smaller ones, offer less resistance, because the increase of surface of the electrodes is greater than the increase of the distance between them. This resistance of the batteries varies with the nature of the liquids in which the electrodes are immersed. It can be easily understood that all liquids have not the same specific power of resistance.

Connection of Voltaic Cells Abreast.—We have seen (Fig. 41) how two battery cells of the same kind may be placed in opposition to each other in such a manner as to counterbalance each other. Let us now take away the galvanometer that we had placed in the circuit of these cells, and we shall still have two cells *joined in opposition.*

Let us consider the two cells thus joined. If the galvanometer be put into communication, on one hand, with the wire connecting the two positive poles and, on the other hand, with the wires connecting the two negative poles, the passage of a very strong current will be observed. The currents of the two cells, which were at first opposed to each other, now flow together in the galvanometer. The two battery cells are then said to be *joined in quantity.*

The metallic piece which connects the two zinc poles may be considered as the negative pole common to both cells and the other as the positive pole common to both cells. It may be observed that the two cells ought to produce the same effects as a single one, in which the electrodes would have a double surface, while the distance between them would remain the same.

The internal resistance offered by the two cells is only half of that offered by each one alone, while the electro-motive force remains the same. This may be demonstrated by placing a third cell, of the same size and kind, in opposition to these two cells joined in quantity. The galvanometric needle does not deflect, which shows once more that the electro-motive force does not depend upon the size of the electrodes, but solely upon their nature.

There is, finally, a third way of joining these two cells, namely, joining them in intensity, of which we have already spoken. This manner consists in uniting the positive pole of one of the cells to the negative pole of the other. In this arrangement the electro-motive force

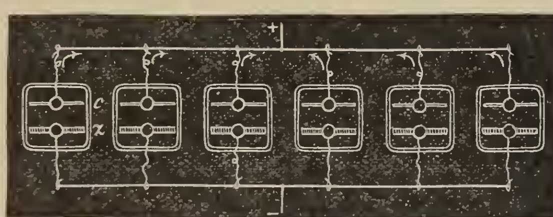


Fig. 43.

of the two taken together is double that of each separately; the resistance is also double.

These different ways of joining battery cells may be applied to any number of cells. If six cells be taken, for instance, and joined in intensity, the electro-motive force of one cell being symbolized by E and its resistance by R, it is evident that a battery of six cells joined in intensity will have an electro-motive force equal to 6 E and a resistance equal to R. If all be joined in quantity (Fig. 43), the electro-motive force of the battery will be E and the resistance $\frac{R}{6}$.

If they be joined by twos in intensity and threes in quantity, the electro-motive force will be 2 E and the resistance $\frac{2}{3}$ R. They may, finally, be joined by threes in intensity and by twos in quantity; the electro-motive force will be 3 E and the resistance $\frac{2}{3}$ R. As long as, in the last combination, there is no connection with any outside circuit, the three cells on the right are in opposition to the three on the left. It is not necessary for me to dwell longer upon the subject, or to make calculations which are, indeed, very simple, to enable the reader to understand

that, with a sufficient number of cells, a battery may be as great, and its resistance as little, as may be desired.

Voltameter.—Before entering upon the study of some of the batteries, it would be well to study a few of the effects they produce. Of all the chemical actions that can be brought about by means of electric currents, the decomposition of water is the most striking. It is done in an apparatus called the voltameter.

Two wires or plates of platinum are placed parallel with each other in a jar containing dilute sulphuric acid. These two electrodes pass through the bottom of the jar, and are attached to binding-screws or terminals to which the wires of a battery are fastened. If a sufficiently energetic current be made to pass in this apparatus, bubbles of gas will be seen to free themselves from the surface of the electrodes. If these gases be collected in proper gas-measuring jars, oxygen will be found in one and hydrogen in the other.

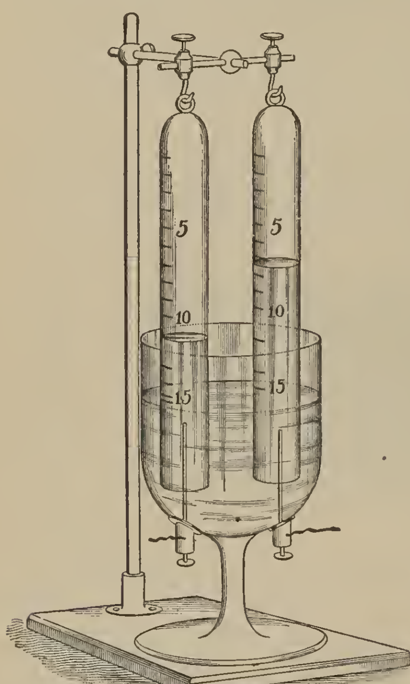


FIG. 44.—A VOLTAMETER.

The electrode by which the current enters the apparatus is called *positive electrode of the voltameter.* It is that which is connected with the positive pole, or, in other words, with the negative electrode of the battery, that furnishes the current. The negative electrode of the voltameter is connected with the negative pole, or positive electrode or generating electrode of the battery. The oxygen which appears upon the positive electrode of the voltameter is termed electro-negative; the hydrogen which is seen at the surface of the negative electrode of the voltameter is termed electro-positive.

In general, every liquid decomposed by the passage of an electric current is called an *electrolyte*, and it is said to be *electrolyzed* so long as the electric action continues. Faraday established, by numerous experiments, the laws of definite electrolysis. Without going into details, suffice it to say that two or three cells joined in intensity produce a current used to electrolyze water; for instance, for each chemical equivalent of hydrogen set free in the voltameter there will be an equivalent of zinc dissolved in each cell of the battery. The law of Faraday

may be said to be the equivalent of chemical work in all parts of the circuit.

If the experiment be made with six cells, instead of with three as indicated above, the quantity of hydrogen set free in one minute will be much greater. An idea of the quantity of electricity is thus obtained, and it can be understood how the instrument called voltameter permits one to measure this quantity. It owes its name to Faraday, who was perfectly justified in so calling it, as it is in truth an instrument of measurement. The same cannot be said of the galvanometer, which it would be better to call galvanoscope; for, in general, it does not measure the intensity of the current which passes through it, and it is only by means of complicated contrivances that any measurements can be obtained from its indications.

Much to our regret, this instrument (voltameter) is not convenient for use. It is unreliable regarding the indications, and often produces false results, on account of the resistance which it introduces into the circuit. It also presents other causes of error.

It is possible to attach a specially-calibrated scale to a galvanometer so that the readings shall be brought directly into current. A galvanometer that has been calibrated in this way is called an ammeter (ampèremeter). From it one can read off the scale milliampères or thousandths of an ampère, and often obtain fairly accurate results.

SECONDARY CURRENTS.

Polarized Electrodes.—If the voltameter be submitted for a short time to the action of a current its electrodes acquire remarkable properties, which may be recognized in the following manner: If the wires are detached connecting the voltameter to the battery, and then connected with the voltameter and a galvanometer, the galvanometric needle will be seen to deflect, thus making manifest the passage of a current furnished by the voltameter. The direction of the current is such as to show that that which was the negative electrode of the voltameter in the experiment with the battery has become, in the experiment with the galvanometer, the positive pole of this new source of electricity. In other words, the current flows in one direction in the first case and in the opposite direction in the second. It may be said that the voltameter has been charged with part of the current of the battery, and returns this current in the contrary direction.

It has been said that the *electrodes are polarized;* which is true, for they have been rendered capable of acting as poles. This is the origin of the expression which we have already used,—polarization of the electrodes. The current furnished by the polarized electrodes of the voltameter in the conditions indicated above is called a secondary current, the voltameter acting as a secondary battery. The secondary current thus obtained lasts but a short time; its intensity is seen to diminish

rapidly from the moment it begins to circulate in the galvanometer, and is soon reduced to nothing.

Polarization of a Voltaic Cell.—Let us now turn to the consideration of the objections to the earlier forms of batteries. It will not be difficult to understand the origin of their drawbacks, and how they have been overcome. An ideal battery should maintain a constant electro-motive force through the whole time of its action; its resistance should be as slight as possible; the materials of which it is constructed should be such as not to become rapidly changed in their character during its action, so that its life may be as long as possible; and there should be little or no chemical action going on when the circuit is broken, so that the entire energy of chemical change shall be concerned in or incident to the production of the current. The first forms of batteries, which were single-fluid batteries, failed to meet any of these requirements.

The following instructive and striking experiments illustrate to us the principal difficulty in the way of meeting the first: If the current furnished by a voltaic cell (one of Wollaston's, for instance), with well-amalgamated zinc, be examined by means of a galvanometer, the intensity is seen to diminish from the moment the circuit is closed. This diminution is very rapid if the circuit have but very little resistance; it is, on the other hand, very slow if the circuit offer great resistance. If, after having allowed the current to flow for five minutes, for instance, the circuit be left open for five minutes, it will be seen, when again closed, that the current has nearly assumed its first intensity. It can be said, then, that the battery when not at work regains its initial power.

From these observations it has been shown how it is possible to use the sand-battery for a number of years in the telegraph service, the telegraph lines offering great resistance, but only requiring intermittent currents. By closer observation we find that, while in the circuit, different circumstances of the phenomenon will be seen which will throw a great deal of light upon the causes to which it must be attributed. At first bubbles of hydrogen are seen to form themselves upon the copper electrode, as we have already stated; this will lead to the belief that imperceptible bubbles form themselves upon the entire surface in such a way as to interpose more or less completely, between the electrode and the liquid, a gaseous layer. Thus, apparently, the principal cause of the diminution of the intensity of the current should be sought at the surface of the copper electrode.

The following experiments will serve to demonstrate this: If, after a marked diminution in the deflection of the galvanometric needle, the electrodes be shaken without lifting them out of the liquid, the current will be seen to partly recover the force it has lost. The same is observed if the liquid alone be shaken without moving the electrodes, and, consequently, without changing the extent of the immersed surface. The moving of the copper electrode alone will show, as a result, the recovery

of the lost force. On rubbing the copper—without taking it out of the liquid—with a small brush the same result is noticed.

In these three experiments we find that the disappearance of the bubbles of hydrogen from the surface of the conducting electrode is accompanied by a renewal of the intensity of the current. If, on the other hand, the zinc electrode alone be agitated, no perceptible modification in the decrease of the current takes place.

Consequently, there can be no doubt as to the importance of the phenomenon which takes place on the surface of the copper electrode. This diminution of intensity just observed may be attributed to two causes: either to the increase in the internal resistance of the battery, or to the decrease in the electro-motive force; in fact, the two causes are present at the same time. That the resistance increases cannot be doubted, since the active surface of the copper electrode is diminished; but a simple and direct demonstration of this does not seem easy to obtain. That the electro-motive force is diminished is extremely easy to prove. For this experiment the method of opposition is employed which we have already described,—and a method which is as convenient for the comparison of electro-motive forces as are scales for the comparison of weights.

The instant the electrodes are immersed in the liquid and the battery begins to work, the electro-motive force attains its maximum intensity. Take two identical battery cells and close the circuit of one of them for five minutes, leaving the other inactive. At the expiration of that time, place the one that has been working in opposition to the fresh one, and interpose a galvanometer in the circuit, and the result will show the superiority of the electro-motive force of the fresh cell. If, now, these two cells be made to act separately, each upon itself,—that is, without the insertion of any resistance,—for five minutes, it will be found, at the end of that time, by placing them in opposition, that the second one still possesses greater electro-motive force than the first one.

It can also be shown that the electro-motive force of a voltaic cell can, by constant action, be reduced one-half. It is admitted that the diminution in the electro-motive force of batteries is due to the production of an electro-motive force (upon the surface of the negative electrode) contrary to that of the principal current. This view is founded upon the facts which have been advanced about the electro-motive force found in a voltameter, from electrodes of which gases are given off.

It may be shown by a direct experiment that the conducting electrode of a weakened battery has acquired peculiar properties. It is only necessary to immerse in the liquid a second plate of copper and to connect the two with a galvanometer. The passage of a current is thus made manifest, and its direction shows that the copper plate acts as the soluble electrode, or electro-positive, when compared with the other, which assumes the part of a conducting electrode, or electro-

negative. This current decreases from the moment it is established, and soon becomes imperceptible. Thus the electrode which was electro-negative in the voltaic cell before and during its weakening is electro-positive in the test-cell of two copper electrodes. Finally, if after the above experiment the voltaic cell be re-established, the electrode assumes its original intensity, at least for a moment, and then begins to weaken again, as in the first instanee.

It is then that the conducting electrode is said to be in a state of *polarization.* Such is the phenomenon of the polarization of the negative electrode of batteries, a knowledge of which is so important. We know that the slighter the polarization the better the battery. There is still much scope for improvement in batteries, although much attention and ingenuity have been concentrated upon securing for them constancy of current and absence of polarization. The prineipal aim of inventors has always been, and still is, to *depolarize the electrode.*

It has been established that the *polarization* remains the same when the size of the cell and the intensity of the current are in proportion to each other. It is here necessary to define polarization. Polarization is the difference between the electro-motive forces in a polarized battery and the electro-motive forces in a depolarized battery.

It can be understood, indeed, that the quantity of hydrogen given off upon the negative electrode is in proportion to the intensity of the current, and that, if this quantity distribute itself upon the surface of an electrode also proportional, the degree of thickness of the deposit will be the same over the entire surface, and consequently its intrinsic action will not have changed. The practical conclusion of this law is that polarization will be less in a battery having larger electrodes than in one with smaller electrodes, though the total resistance be the same.

Polarization in a Battery of Several Elements.—So far, each time the polarization of the negative or conducting electrode of cells has been spoken of, the existence of one cell only has been tacitly implied; and, further, that the current whieh produced the polarization was the current of the cell itself. Under ordinary circumstances this is not so; several elements are generally joined in intensity, and the current which flows in each one is furnished by the entire battery.

If we place ten cells, each having ten units of resistance, in a circuit of one hundred units (total resistance, two hundred units) it is clear that the current will be more intense than if nine of the ten cells were taken away; consequently, the eurrent which produces the polarization in each cell will be more energetic than if there were only one cell. The result is that its weakening due to polarization is more marked in cells which are joined in intensity than in separate cells.

Explained otherwise, when a current passing through a cell is more energetic than the current which the cell itself produces, the weakening of the current takes place under the following circumstances: At first,

hydrogen is given off upon the copper, and produces that which we have termed polarization of the cell. But afterward, when the greater part of the acid is converted into sulphate of zinc, the sulphate itself becomes electrolyzed, and the reduced zinc deposits itself upon the copper. If, at last, this deposit cover the entire surface of the copper, it can be easily seen that the two electrodes will become identical, and, consequently, it is no longer a battery cell. Cases have been adduced, experimentally and otherwise, where some cells of a battery not only cease to produce current in the right direction, but actually produce a reverse current.

The Study of Batteries and their Classification.

We have now reached a point where it is possible to study the different batteries and to draw comparisons between them. Up to this time we have studied only the voltaic battery and the modifications in its arrangement. Let us now take a look into those batteries, which have sprung up from the first cell, analogous to, but differing more or less from, its germ (the voltaic cell).

It will be seen how Volta, notwithstanding his imperfect means, had the happy thought to choose the elements which have been used ever since.

What are the essential conditions of a good galvanic cell? 1. It should have high electro-motive force. 2. It should have low internal resistance, so that no energy should be wasted within the cell. 3. It should give a constant current, and thereby prevent polarization. 4. The material for its consumption should be cheap and readily obtainable. 5. The cell should require no inspection or supervision to keep it in good order until all the energy of its chemical affinities is exhausted. 6. The form and dimension of the cell should be convenient, and no noxious chemical products should be formed on it by action.

No battery or one form of cell fulfills all these conditions; but as there are many varieties, it is possible to select certain cells as especially adapted to particular purposes and compare them by their standard. A great many cells have been devised from time to time, and, in order to place them in their proper category, it is necessary to classify them. The following is the latest scientific classification: 1. The closed-circuit batteries. 2. The open-circuit batteries. 3. Batteries without a depolarizer. 4. Standard of electro-motive force.[1] 5. The storage battery. 6. The medical galvanic batteries of several makes.

What is the distinction between an open- and closed- circuit battery? It has been seen[2] that the inconstancy of the current furnished by a battery through a fixed resistance is largely accounted for by polarization

[1] Several specimens of each of the classified batteries will be described and studied.

[2] Some of these descriptions of cells are taken from the valuable little work on Primary Batteries, by H. S. Carhart, A.M., of Michigan. 1891.

due to cell. That which stops polarization, either by removing the hydrogen as fast as it is formed or by preventing altogether its disengagement, is called a *depolarizer*. The distinction between open- and closed- circuit batteries depends chiefly upon the nature and action of this depolarizer.

A battery is entitled to be included in the closed-circuit type only when it is capable of working in a closed circuit of moderate resistance for a considerable period with but slight diminution in the intensity of the current. The difference is thus clearly established, between it and those cells that are adapted to stand on open circuit, without wasteful local action, and that furnish current only at intervals and then only of a few seconds' duration.

In a closed-circuit cell the depolarizer must act with sufficient promptness and efficiency to completely prevent polarization, thus removing this cause of the decrease in the current.

In open-circuit batteries the depolarizer may, indeed, be entirely absent, or it may act with so much sluggishness as to be unable to prevent polarization taking place to some extent during the action of the cell, but it destroys polarization after the circuit has been again opened. The promptness with which a cell recovers from a depression of its electro-motive force by polarization is a good criterion of the efficacy of this class of depolarizers. Batteries provided with such depolarizers occupy an intermediate position between those with a promptly-acting one and those with none at all, of which the simple voltaic element is the type. The more-efficient depolarizers, in general, are liquid; the less-efficient or slower-acting ones, with only a few exceptions, are solid. The first class must be employed when a continuous current is required, especially if the current is of considerable strength. If but a small current is taken from a cell through a high resistance, then a solid depolarizer will suffice. But batteries with no depolarizer for the removal of hydrogen, or an equivalent, are adapted only to open-circuit use, in which the circuit is to be closed for only a few seconds at a time.

CLOSED-CIRCUIT BATTERIES.

The Daniell Battery.—This is the battery which claims for itself the underlying principle of all constant batteries. It was invented by Professor Daniell, of Edinburgh, in 1836. It (Fig. 45) consists of a copper plate, *C*, dipping into a solution of copper sulphate contained in a glass or glazed, highly-vitrified, stone-ware jar, *J*, and a zinc plate or rod, *Z*, to which a copper wire or strip, *W*, is soldered, dipping into either dilute sulphuric acid or a solution of zinc sulphate, the two solutions being separated by a porous partition, *P*, made of unglazed earthenware, and called "a porous pot." The electro-motive force of a Daniell cell, with all its modifications is, roughly, 1.1 volts, but it varies from about 1.07 volts to 1.14 volts, depending upon the densities of the solutions of copper and zinc

sulphate. With *equidense* solutions and with plates of pure zinc and copper, the electro-motive force is 1.104 volts. This value is increased by increasing the density of the copper-sulphate solution, and is diminished by increasing the density of the zinc-sulphate solution, and is scarcely at all affected by the *ordinary* atmospheric changes of temperature.

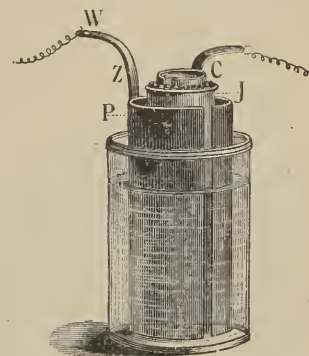


FIG. 45.—DANIELL CELL.

The Daniell battery gives a constant electro-motive force, and retains a nearly constant resistance. The resistance of the cell varies with the area of the copper and zinc plates immersed in the liquid, the distance between the plates, and the thickness and constitution of the walls of the porous cell. With a cell about seven inches high, of the relative dimensions shown in the accompanying figure, the resistance may be as low as $\frac{1}{3}$ ohm when the solution in which the zinc plate is immersed is dilute sulphuric acid of a specific gravity of about 1.15 at 15° C., while some Daniell cells with porous pots and small zinc plates are used having a resistance of as much as 10 ohms. The electro-motive force of the Daniell, or of any other form of cell, is quite independent of the size of the various parts of the cell, or of the cell as a whole, and depends solely on the materials employed in its construction.

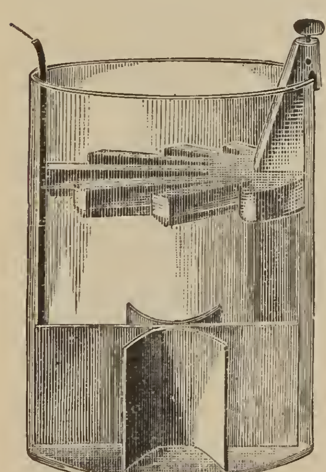


FIG. 46.—GRAVITY BATTERY.

On account of the constancy of the Daniell cell, which is caused by electro-motive force, in the practice it may be taken as a unit and can be compared with others. The British Association has adopted a unit differing very little from this one, and has given to it the name of *volt.* The cell in which the electro-motive force is exactly equal to the volt differs but slightly from that of Daniell.

The Gravity Battery.—This battery is a simple modification of the Daniell, designed to dispense with a porous cup. It takes its name from the fact that in it the zinc and copper sulphates are separated by their difference in density. One form of this battery is shown in Fig. 46. This cell always keeps in better condition if a closed circuit be maintained through a high resistance when the battery is not in use.

The Grove Battery.—The Grove battery consists of a cleft cylinder

of zinc immersed in dilute sulphuric acid (1 to 12) and a thin plate of platinum in nitric acid, contained in a porous cup. The platinum electrode, being surrounded by the nitric acid, decomposes, oxygen is set free and forms water with the polarizating hydrogen, and nitric oxide is given off. The battery thus modified is without polarization; in other words, it is constant. This battery dates from 1839.

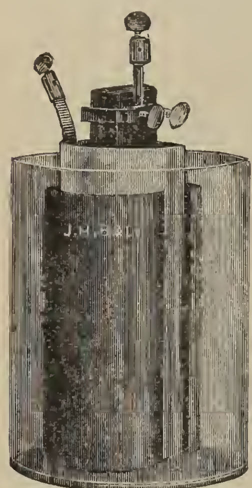


FIG. 47.—BUNSEN BATTERY.

The Grove battery has the advantage of electro-motive force and low internal resistance. Such a cell is capable of giving 12 ampères on short circuit, or through an external circuit of no appreciable resistance. Before the introduction of dynamo-electric machines and the storage battery, 40 Grove cells served for an arc light. It is found that electro-motive force is intermediate between that of a Grove and that of a Daniell battery.

The Bunsen Battery.—After the invention of the Grove battery, Bunsen modified it by substituting a prism of baked carbon for the platinum. The electro-motive force is slightly less than that of the Grove.

The Bichromate Battery.—This battery is employed very extensively in laboratories, and presents some very great advantages. The resistance is very slight on account of the short distance between the electrodes, and, moreover, the waste of the zinc is suppressed during the intervals between experiments, as it is withdrawn from the liquid; thirdly, polarization is slackened by the comparatively large surface of the carbon electrode; fourthly, the quality of the liquid is considerable on account of the special form of the lower part of the bottle; and, lastly, the charging and cleansing is extremely easy. But in spite of these advantages the battery gives a powerful current for only a short time, after which the intensity is seen to diminish. It is therefore suitable only for experiments of short duration.

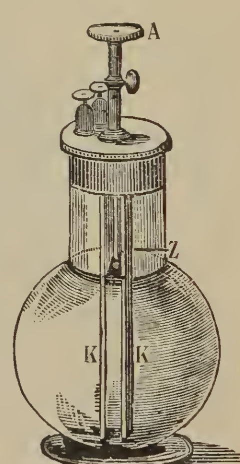


FIG. 48.—BICHROMATE BATTERY.

The accompanying cut represents one of the forms of this cell. The zinc is attached to a rod, *A*, by means of which it can be drawn out of the liquid when the battery is not in use. The carbon plates are fastened to a metallic clamp, which is attached to

the hard-rubber top of the cell. The top of the zinc is covered with an insulating strip to prevent direct contact with the carbons. Many other forms of plunge batteries have been the outcome of this invention.

The Copper-Oxide Battery.—It has been remarked that, in general, the best depolarizers are liquid. There are, however, two exceptions to this, which exhibit notable efficiency. They are the oxide of copper and the chloride of silver. Both these solids readily give up their non-metallic element to nascent hydrogen, and the reduction to the metallic state makes them excellent conductors. This copper-oxide cell was introduced by Lalande and Chaperon. It has a capacity for work per unit weights greater than any other cell, either primary or secondary.

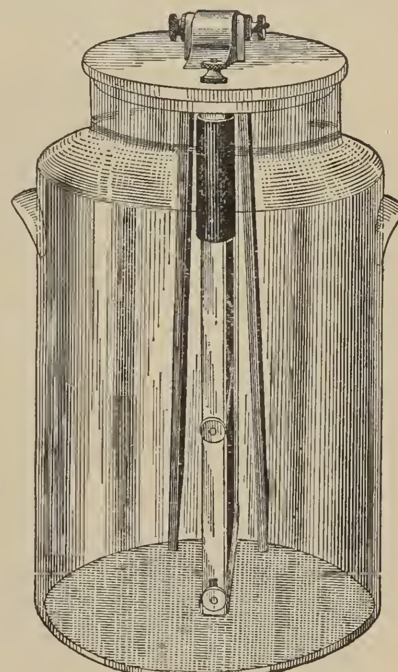


Fig. 49.—Edison-Lalande Copper-Oxide Battery.

Mr. Thomas A. Edison, recognizing the good qualities of the copper-oxide as a depolarizer, has devised a form designed to meet most of the objections which may be made to it. The copper oxide is employed in the form of a compressed slab, which, with its connecting copper support, serves also as the negative plate. Two of these plates are inclosed in a copper frame, on the longer arm of which is the binding-post. One or two of these copper-oxide plates are used, according to the size and capacity of the cells. The weight of the oxide plate for a 15-ampère-hour cell is two ounces, and for a 600-ampère-hour cell two pounds. The figure, as shown, is a 600-ampère-hour cell complete. The cover is porcelain, with small openings for the zinc and copper terminals. Since this cover does not exclude the air, the formation of a carbonate is prevented by pouring on top of the solution of caustic potash a small quantity of heavy paraffin-oil, so as to form a layer about one-fourth of an inch deep. If it is not used, the life of the cell is reduced fully two-thirds.

The Edison-Lalande cell has been subjected to a number of stringent tests at the Edison laboratory,[1] and is also being put to the test of doing

[1] The cuts and notes illustrating these laboratory tests of the Edison-Lalande battery are taken from the private laboratory register of Mr. Edison. I found it important to introduce these detailed accounts of this cell, that every one might judge its value for himself. It is the only perfect closed-circuit battery in existence, and can be highly recommended to the profession for all medical and surgical purposes.

hard and continuous work on the lines of telegraph, railway, and telephone companies, with the best of results. This battery is now in the hands of the most prominent men of our profession for all kinds of work. I can recommend it as the only battery for cautery and motor work. Those who have not seen it in action should certainly find an opportunity to examine it. The only drawback is in the cleansing and refilling, in which caution must be exercised on account of the caustic potash, although this difficulty is now being overcome by using sticks instead of a solution of potash. The results of these laboratory tests are shown in the curves given herewith (Fig. 50).

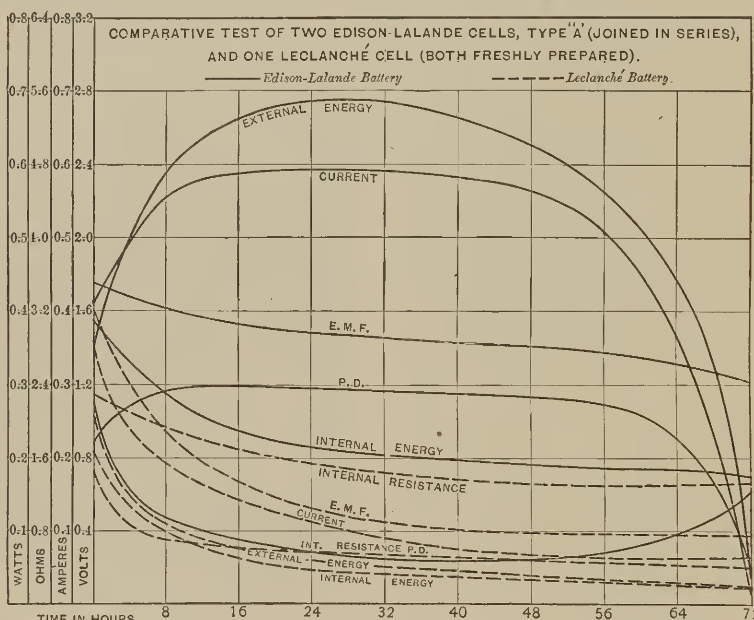


FIG. 50.

In this test the batteries were so arranged as to be alternately thrown into circuit with a resistance coil. The periods of rest and work were of five minutes' duration. When the Leclanché was resting the Edison-Lalande was working, and *vice versâ.*

The 300-ampère-hour cell, which may be taken as a typical example, stands eleven and one-fourth inches high by five and three-eighths inches in diameter. It has an internal resistance of 0.025 ohm; the electromotive force of the cell on continuous hard work is 0.7 volt, and on light work 0.75 volt. The initial electro-motive force is 0.9 volt, soon falling, however, to the normal standard, where it remains practically constant during the life of the cell. On open circuit there is little or practically no action on the zinc, and positively none when the latter is pure. The

action of the cell is admirably shown in the accompanying curves (Fig. 51). Fig. 52 represents the results of careful tests made at the Edison laboratory upon cells picked out at random from among a large number. In this test four 300-ampère-hour cells were joined in series in circuit with a resistance of 0.8 ohm, and gave the following results: Weight of zinc before test, 10,017 grammes; weight of zinc after test, 8567 grammes; total loss, 1450 grammes. Calculated loss from output, 1444 grammes; loss by local action, 6 grammes. Mean current, 2.76 ampères, 2.8 volts; total run, 298 ampère-hours. The loss was calculated as follows, taking the chemical equivalent of zinc as 0.0003367, based on the latest researches

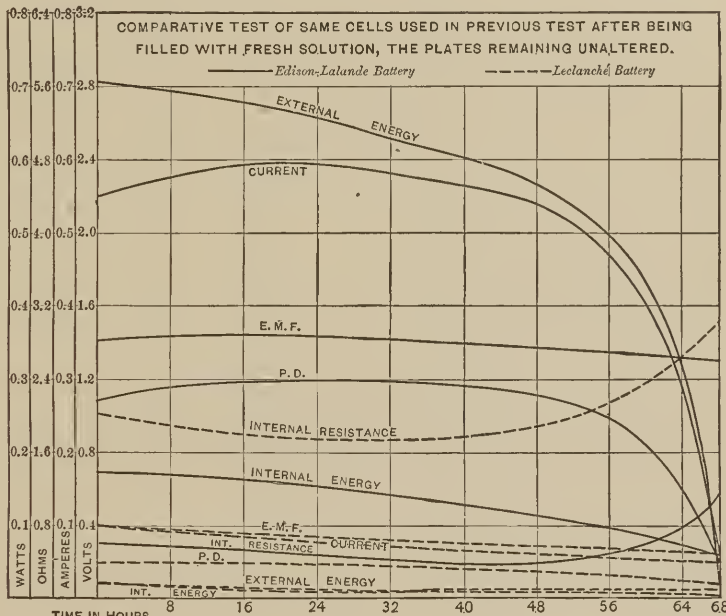


FIG. 51.

of Rayleigh and Kohlrauch: $276 \times 108 \times 3600 \times 0.0003367 = 361$; $361 \times 4 = 1444$.

Fig. 53 exhibits results of a comparative test of Leclanché and Edison-Lalande batteries in connection with Blake transmitter. Both batteries had been closed through transmitter for twenty minutes; the circuit was then opened, and the increase in electro-motive force was noted at regular intervals.

The test as here shown extended over a period of one hundred and eight hours, and both the current and electro-motive force remained practically constant. It will be noted, however, that the external available energy continued to increase for nearly half the period of the test, owing to the almost constant decrease in the internal resistance of the

cell, which is also evidenced by the curve representing the internal energy, which fell rapidly from the start.

This decrease in internal resistance is due to the fact that the reduction of the oxide of metallic copper at the surface of the negative plate causes the formation of an excellent conducting surface, the production of which, however, requires a few hours' work in a cell freshly set up. In the latest form of the *Edison-Lalande cell the improvement has been effected* of reducing a thin film of copper on the oxide superficially, before placing in the cell, to make the initial internal resistance lower. In reading the figures at the left those referring to the watts, ohms, and volts must be divided by four in order to reduce them to the corresponding values for one cell. During the test the cells were connected through a resistance of 0.8 ohm.

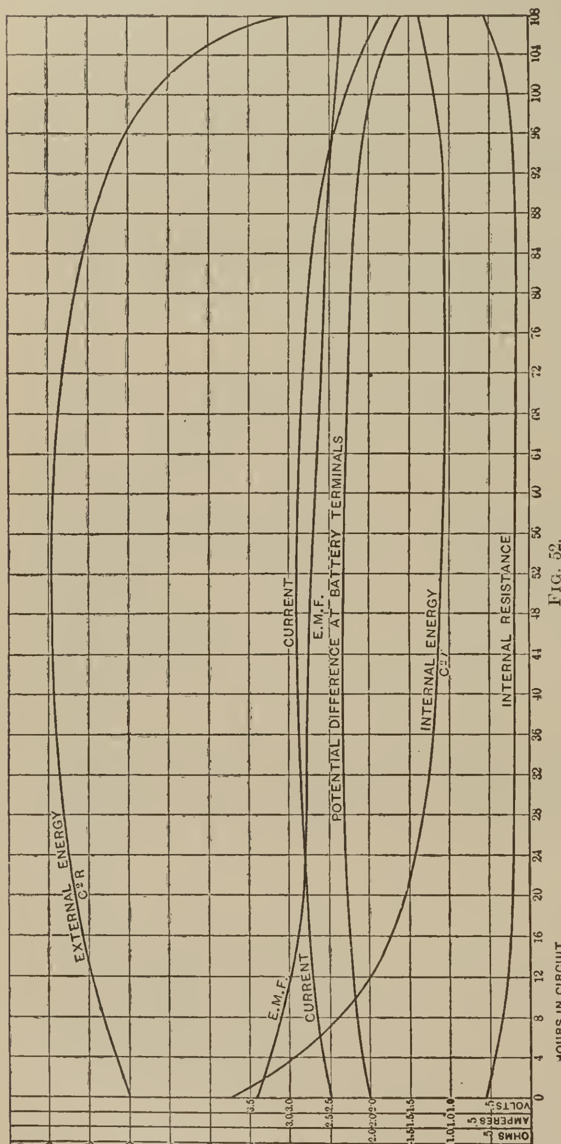


Fig. 52.

I am convinced that wherever this battery is used it will prove itself possessed of undeniable advantages over all others.

The Chloride-of-Silver Cell.—Marie Davy appears to have been the first to suggest the use of silver chloride as a depolarizer (about 1860), although it owes its present prominence to the investigations of Warren de la Rue.

The elements are zinc and the silver chloride, the latter of which is readily reduced to metallic silver by nascent hydrogen. The exciting fluid of De la Rue's battery is ammonium chloride, and contains 23 grammes to 1 litre of distilled water.

The initial electro-motive force of a silver-chloride cell is about 1.1

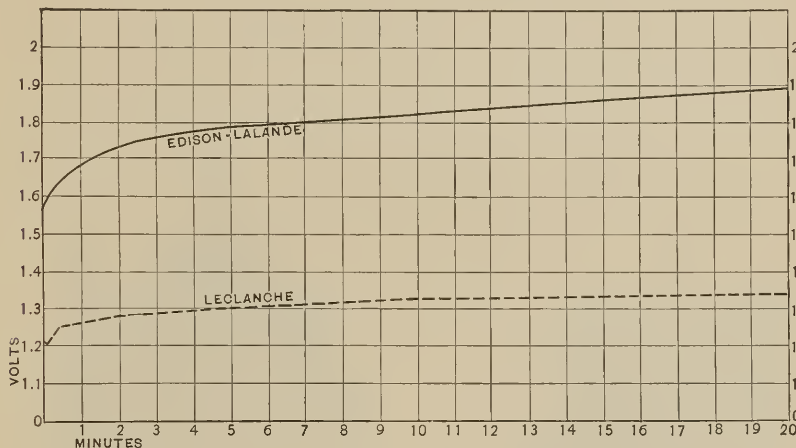


FIG. 53.

volts. Its internal resistance falls rapidly upon first closing the circuit, on account of the reduced silver. It polarizes but slightly, and recovers promptly. It is employed chiefly for testing purposes. It is now much used by physicians. The Gaiffe and other chloride-of-silver batteries are very extensively used for induction coils, or to furnish continuous currents for medicinal purposes. This is a small cell, hermetically closed in ebonite boxes having screw-tops. This battery is transportable, and has no free liquid, the two electrodes being separated by six or eight sheets of blotting-paper saturated with a solution containing 5 per cent. of chloride of zinc. Gaiffe formerly employed powdered chloride of silver, but he now seems to prefer the melted silver. There are also other forms of this battery on the market.

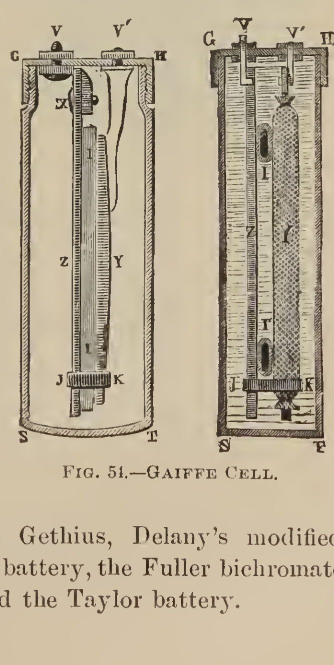


FIG. 54.—GAIFFE CELL.

Among other varieties of the closed-circuit batteries may be mentioned the Gethius, Delany's modified gravity cell, Sir William Thompson's tray battery, the Fuller bichromate battery, the Partz acid-gravity battery, and the Taylor battery.

OPEN-CIRCUIT BATTERIES.

The Leclanché Cell.—This one stands at the head of the open-circuit batteries in which a solid depolarizer is used. It bears the name of its inventor, Leclanché. The metallic oxide had been proposed as depolarizers previous to the invention of this cell, but without practical results. Thus, with zinc in dilute sulphuric acid and platinum, surrounded by the peroxide of lead in a porous cup, Brets found an electro-motive force of 2.4 volts. During thirty minutes' short circuit this fell to 1.4, but recovered, after five minutes' rest, to 2.16. It is evident that this high electro-motive force is due not only to the oxidation of the zinc, but to that of the hydrogen as well, both chemical processes contributing to the electro-motive stress in the same direction. The chief disadvantage

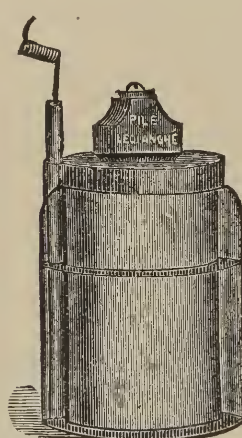


FIG. 55.—LECLANCHÉ CELL.

FIG. 56.

in the employment of lead peroxide as a depolarizer lies in the fact that the reduced lead is converted into lead sulphate. This accumulates on the negative pole, and has the effect of largely increasing the internal resistance of the cell.

The typical Leclanché cell with its porous cup has a glass jar, molded with a lip, and in it the zinc rod is placed. The carbon plate is usually surmounted by a lead cap cast on the carbon and holding the binding-post of the positive terminal. The cut exhibits a new connection, designed to avoid corrosion of the lead cap. The size of the zinc rod, which never exceeds half an inch in diameter, indicates larger internal resistance, and shows that the cell is designed to furnish only small currents through considerable external resistance. The amount of energy held potentially in the cell is represented approximately by the weight

of the zinc. The exciting liquid is ammonic chloride. The initial electro-motive force of the Leclanché cell varies from 1.4 to 1.7 volts, and the internal resistance from about 0.4 to 2 ohms.

There are several modifications of the Leclanché cell on the market, each one possessing an advantage or a disadvantage over the other. Three of these, as the prism Leclanché, the closed Leclanché, Leclanché with carbon cup, are shown in Figs. 56, 57, and 58.

Among the open-circuit batteries there are several known to us of the Roberts peroxide battery, the sulphate-of-mercury battery, and the Fitch chlorine battery. They all have their special uses.

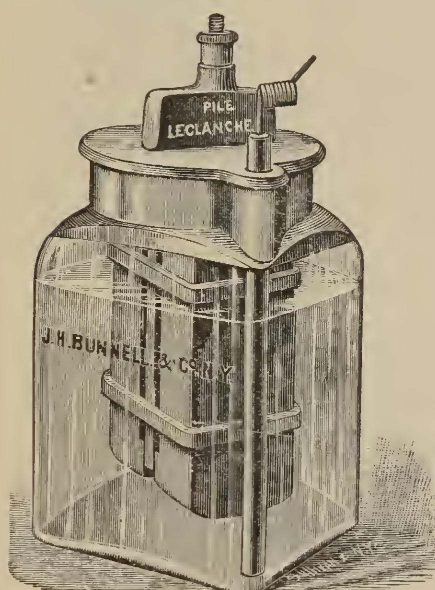


Fig. 57.

Fig. 58.

BATTERIES WITHOUT A DEPOLARIZER.

The Smee Cell.—This is the oldest battery of any practical value without a depolarizer. The positive plates of this cell are zinc, inclosing between them, with proper insulation, a negative of thin silver corrugated and covered with platinum in a very finely divided state. The excitant or electrolyte is dilute sulphuric acid; and the purpose of the roughened surface of the silver is the mechanical dislodgment of the hydrogen as fast as it is released at the negative plate, hydrogen being found to be much more easily detached from a rough surface than from a smooth one.

The Law Battery.—Among batteries without depolarizers may also be found the Law battery, the diamond carbon battery, the cylinder carbon battery, and the Gassner dry battery, all known to us.

The Gassner Cell.—One of the oldest cells of the dry type without a depolarizer is that of Dr. Gassner. The zinc composing the positive element is the containing vessel. It is usually covered with paper, or inclosed in a paper box. The negative element is carbon, and occupies about one-half the space in the cell. The paste, which is filled in between the zinc and the carbon in the Gassner cell, is made of a composition. The initial electro-motive force of this cell varies but little from 1.3 volts. It polarizes very rapidly on so low an external resistance as 5 ohms, while the internal resistance, which is different for cells of different size, is very irregular during the working of the cell. Such a cell should be employed only for intermittent service, where the circuit is kept closed for short periods only. In such situations it will doubtless prove efficient and durable. Its convenience, particularly in the hands of unskilled persons, is much in its favor.

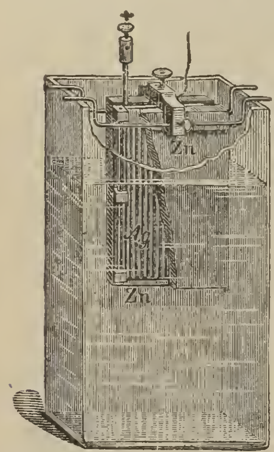


Fig. 59.—Smee Battery without Depolarizer.

Fig. 60.

BATTERIES WHICH HAVE STANDARD OF ELECTRO-MOTIVE FORCE.

The *Latimer-Clark cell* is one of the best specimens of the standard cell. The metallic elements are pure zinc in zinc sulphate and pure mercury. The normal electro-motive force of this cell is 1.45 volts at 66° F., diminishing very slightly as the temperature rises. The Latimer cell is the most useful one for testing, although it is used almost solely for the purpose of supplying a reliable standard of electro-motive force. It possesses a remarkably constant electro-motive force, and the amount of its variation between different cells is generally exceedingly small.

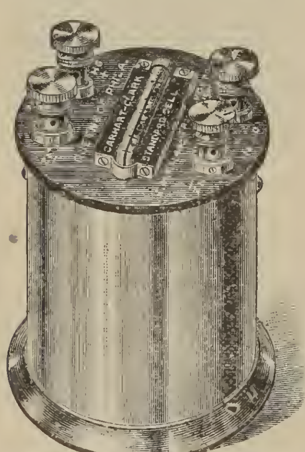


Fig. 61.—Clark Standard Cell.

The original Clark cells exhibited certain abnormal and irregular values, both of electro-motive force and temperature coefficient. A

thorough investigation of it was therefore undertaken by Lord Rayleigh, and the results published. His investigations gave birth to another cell named after him, the Rayleigh cell. There are also several other standard cells known as the oxide-of-mercury cell, described by M. Gouy in 1888; Sir William Thompson's standard Daniell cell, Lodge's standard Daniell cell, Flemming's standard Daniell cell, and the chloride-of-lead standard cell.

STORAGE BATTERIES.

In another part of this work I have already said that a voltameter submitted to the influence of an electric current for a moment becomes capable of furnishing a current contrary to the exciting current. This capital fact has enabled me to show, under one of its plainest forms, the phenomenon of the polarization of electrodes.

The current furnished in this manner by the voltameter is a secondary

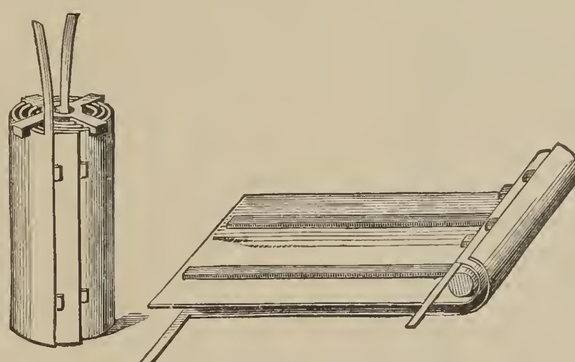


FIG. 62.—GASTON PLANTE SHEET.

current, and the apparatus becomes a secondary element. The current may be said to have been furnished by the battery and returned by the secondary element. The study of this question dates from the investigations by Gautherot, as early as 1801. Shortly afterward the first secondary battery was devised by Ritter, of Jena. Following on the invention of the voltaic pile, it has been found that if an oblong strip of wet paper has its extremities in contact with the poles of the pile each half of the slip will be electrified, and if it be removed from contact with the pile by a rod of glass or other non-conductor its electric state will continue. This was observed by Volta, and, according to Dr. Lardner (writing in 1841), was the means of suggesting to Ritter the idea of his secondary pile, which consisted of a series of discs of a single metal, alternated with cloth or card moistened in a liquid by which the metal would not be affected chemically. If the extremities of such a pile be put in connection by conducting substances with the poles of an insulated voltaic pile, the pile will receive a charge of electricity in a manner similar

to that produced by the band of wet paper, one-half taking a positive and the other a negative charge, and after its connection with the primary pile has been made it will retain the charge it has thus received. The secondary pile, while it retains its charge, produces the same physiological and chemical effects as a voltaic apparatus.

In 1859 M. Gaston Plante made a secondary cell based upon the principles above briefly sketched. Instead of plates of platinum he used plates of lead, rolled as shown in illustration (Fig. 62). The consequence was that, when the current passed through these plates, the oxygen produced at one plate combined with the metal and deposited lead oxide; the hydrogen, as before, remaining free on the other plate. By this means a cell was produced, in which, after the charging current was removed, the elements of lead and lead oxide remained. These being connected yielded a current for a short time; only, however, on account of the little of the oxide produced,—a mere film on the surface. Plante thereupon devised his so-called "forming" process, which consisted in first charging his plates, then discharging, then charging again with the battery current reversed, and so on, increasing intervals of rest being left between the operations, until finally he produced, through the repeated oxidation and subsequent reductions of the oxidized material to a metallic state, very porous or spongy plates. These, by reason of their porosity, exposed a very large surface to the oxidizing action of the current, so that the result was the same as if he had charged a plate of great superficial area.

We know that when batteries are connected in multiple arc—that is, all the zinc plates together and all the copper plates together—then the plates of each kind act as one larger plate, the surfaces of all being connected. Plante found that if he charged a number of secondary cells connected in this way, and, after the charging, arranged his cells in series, —that is, the positive plate of one connected with the negative plate of the next, and so on,—he could obtain very powerful currents for short periods of time.

In 1880 M. Camille Faure covered Plante's lead plates with red-lead, and then put them in little flannel jackets. The peculiarity of the red-lead is that, on sending a current through it, it is easily changed into spongy lead; so that, instead of the "forming" operation taking weeks and months, it can be done in a few days, or even hours. This discovery apparently removed the chief obstacle to Plante's cell becoming of commercial value, and, when announced, was hailed as an extraordinary advance in electricity.

Since 1880 a great many patents have been obtained for secondary batteries, and they now exist in many forms. Mainly, however, the efforts of inventors have been directed to reducing the weight of the cells and to devising new ways of holding the red-lead on the plates. Brush packs his red-lead, or other active material, in a frame of cast-lead

containing slots, cells, or openings. Sellon also made a plate with receptacles for containing and holding the active material.

The storage battery at the present time is simply a subject for further research and invention. No form of it exists in which grave defects are not observable. The value and efficiency of many of the cells offered on the market have been overestimated and often greatly misunderstood, and we find none more eager to grasp at possible improvements than those who to-day most loudly proclaim the great merit of their own particularly-advertised contrivances. This not infrequently represents the hope that the large amount of capital already risked may, by some stroke of good fortune, be redeemed.

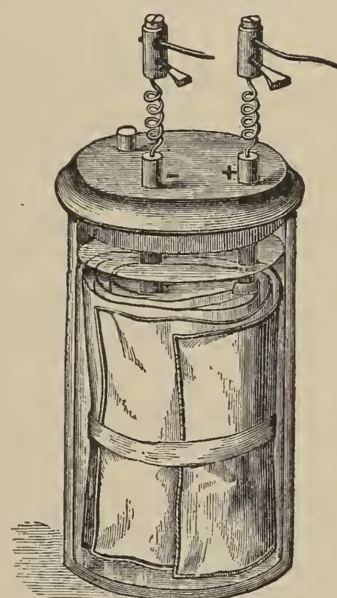


Fig. 63.—Faure's Modification of the Plante Cell.

The commonest defects of the storage cell are "needling," "buckling," and "disintegration." "Needling" is the formation of the so-called "lead-tree,"—fine spiculæ of metal between the electrodes, which cause short-circuiting and rapid waste of current. "Buckling" is the deformation or bending of the plates themselves, by which one plate often comes in contact with another, and short-circuiting again follows. "Disintegration" and "buckling" also are usually due to chemical changes in the electrodes; the plates, disintegrating in time, drop to pieces. Besides these difficulties certain solutions cause very high internal resistance in the cell, as well as a variety of other disadvantages.

One of the best forms of storage battery is that devised by Mr. Willard E. Case, in which he uses a neutral liquid, from which he deposits metal on one electrode while peroxidizing the other. Mr. Case's investigations in the storage battery have led him to the remarkable discovery that heat can be directly converted into electricity in the galvanic cell. He places in his cell an electrode of tin, an electrode of carbon, and a liquid which at ordinary temperature will not attack either electrode; therefore, no current is yielded. But as soon as the liquid is warmed—and to do this the cell, which is hermetically sealed at the outset, is merely put into hot water—chlorine is set free from the liquid, and attacks the tin. Then the current starts, and continues until all the tin is converted into chloride. Now, if the cell be allowed to cool, the chlorine will release the tin and return to the liquid, and the cell regains its original state. The chlorine, in fact, is a chemical pendulum, swing-

ing from liquid to tin, again from tin to liquid, as often as the heat is applied and removed. Of course, the cell lasts indefinitely; theoretically, forever. No material is exhausted in it. The temperature is never above that of boiling water. Its electro-motive force is about $\frac{1}{4}$ volt.

In one sense this cell may be regarded as a heat-storage battery; it is really a wonderful, efficient heat-engine, and is not merely a most beautiful, ingenious illustration of the relation and interconvertibility of the natural forces, but an advance apparently destined to be of the highest practical value.

Electrolysis.

Definition of Electrolysis.—The decomposition of a chemical compound, called the *electrolyte*, into its constituent parts by an electric current.

Under the heading of "Voltameter" much has been said regarding electrolysis, but, owing to its importance, I devote another special part to it. We find that in a galvanic battery a chemical reaction takes place,

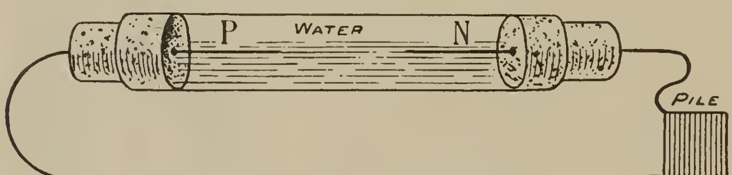


Fig. 64.—Glass Tube and Water.

and the result is the production of an electric current. If, conversely, we place in a decomposable liquid two conducting bodies, and thus enable a current of electricity to pass through the liquid, we shall find that the result is a chemical decomposition. This decomposition by means of the electric current is called electrolysis; the liquid decomposed is known as an electrolyte; and the two conducting bodies are termed electrodes. In a galvanic cell a definite amount of chemical action evolves a current and transfers a certain quantity of electricity through the circuit; so, conversely, a definite quantity of electricity, in passing through an electrolytic cell, will perform a definite amount of chemical work. An electrolytic cell is, therefore, the converse of a voltaic cell. The discovery of the decomposing effects of the electric current was made by accident, and followed almost immediately after the invention of Volta's pile. A series of brilliant discoveries followed within a few years, which at that time were as notable, and many of them as far reaching, as those more recent. One of the earliest and most important of these, because it opened up an entirely new field of research, was the decomposition of water by means of the battery,—an experiment first made by two Englishmen, Messrs. Nicholson and Carlisle. It formed the ground-work of nearly all that was accomplished during the first twenty years of this

century, and it is worth describing in Mr. Nicholson's own words. He says :—

" On the 2nd May (1800) we inserted a brass wire through each of two corks inserted in a glass tube of half an inch internal diameter. The tube was filled with new river-water, and the distance between the points of the wires in the water was one inch and three-quarters. This compound discharger (meaning one of Volta's modified batteries) was applied so that the external ends of its wire were in contact with the two extreme plates of a pile of thirty-six half-crowns, with the corresponding pieces of zinc and pasteboard. (This is the material the Volta battery was made of.) A fine stream of minute bubbles immediately began to flow from the point of the lower wire in the tube which communicated with the silver, and the opposite point of the upper wire beeame tarnished, first deep orange and then black. On reversing the tube the gas came from the other point, which was now lowest, while the upper, in its turn, became tarnished and black. . . . The product of gas during two hours and a half was two-thirtieths of a cubic inch. It was then mixed with an equal quantity of common air and exploded by the application of a lighted waxen thread.

" Platinum was used instead of the brass wires, and gas was liberated at both poles. When collected separately and examined, one proved to be hydrogen and the other oxygen. Other experimenters substituted salts of copper and lead for the water, and found in each case that the pure metal was deposited at one of the poles. These were the beginnings of electro-ehemistry."

The names of Humphry Davy, Cruikshank, Ritter, Nobili, and Faraday must always be at the head of the list as pioneers in this branch of the study. To Faraday we owe very much. Three years later, after his discoveries in magneto-electricity, he supplemented these with the investigations which established the laws of electro-chemistry. He found that the amount of chemical action in the cell is always proportional to the quantity of electricity passing through it, and that the quantities of substances dissolved and set free by electrolysis are in definite proportions by weight, and these proportions are identical with the ordinary chemical equivalents of the substances. From the first law we know that a current of a certain strength will always liberate just so mueh hydrogen, for example, from water, and will cause the solution of just so much zinc in the cell whence the current is derived. To illustrate the second law: Nine grains of water, for example, contain eight grains of oxygen and one grain of hydrogen, and hydrogen and oxygen always combine in these proportions to form water. Now, if we tear apart, so to speak, the constituents of water, we shall always find eight grains of oxygen at the positive electrode and one grain of hydrogen at the negative electrode. Why this happens is not definitely proved, but is the generally accepted theory, that of Grotthüs.

Grotthüs's Theory of Electrolysis.—Explanations regarding what takes place during electrolysis has been frequently attempted, but, beyond more or less probable hypothesis, nothing has been proved. This is not surprising when we consider that the nature of electricity itself is unknown to us. Grotthüs (1805) gave the following explanation of electrolysis: He supposes, in the chemical constitution of water, an atom of hydrogen to be united to an atom of oxygen;[1] that these substances have certain natural electrical tendencies or conditions, hydrogen being a positive body and oxygen a negative body. Whilst constituting water, these natural electricities neutralize each other and hold the two atoms together, the two forces being then in equilibrio. Directly, however, a particle of water is exposed to the influence of the voltaic series, this equilibrium is overset or disturbed, and a particle, A (Fig. 65), at the positive extremity, P, will have its oxygen atom, O, drawn toward P, and its hydrogen atom, H', repelled from it. The one (oxygen) is, by the hypothesis, an electro-negative substance, and the other (hydrogen) an electro-positive substance. Conversely, a particle of water, B, at the negative extremity, N, of the apparatus, will have its hydrogen atom,

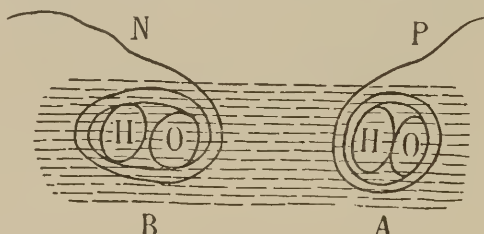


FIG. 65.

H, drawn toward N, and its oxygen atom, O', repelled from it.[2] The two elements of the water will be so far loosened in their state of chemical union. A similar result will ensue in the next succeeding particle of water by the influence of the atoms H' and O', and so on through all the intermediate conducting chain between A and B; that is to say, we shall have what has been termed a polar electrical series, in which all the positive electricities look one way and all the negative electricities the other,[3] as indicated by the positive and negative signs in the next figure, in which A P represents the anode, or positive electrode; C N the cathode, or negative electrode; A, B, C, D being successive particles of water made up of the gases oxygen and hydrogen, O, H, and in opposite electrical states, as denoted by the signs + and —. The atom of oxygen O, particle A (Fig. 66), being, as it were, thus loosened in its combination with

[1] Dalton supposes one volume of oxygen to contain as many atoms as two volumes of hydrogen; so that, although we suppose the gases united atom to atom, still, taken as volumes, they are united in the proportions of 1 to 2.

[2] Rudimentary Electricity (16), p. 13: "Similar electricities repulse and opposite electricities attract each other."

[3] *Ibid.* (38), p. 45.

the hydrogen atom *H*, the positive wire, *P*, by neutralizing its negative electrical energy, may either combine with it or set it free altogether under the form of gas. Similarly, the negative wire, *N*, may set free the hydrogen, *H*. Directly, however, the first oxygen atom, *O*, is evolved, and its associate hydrogen, *H*, left alone, then this same hydrogen, *H*, effects a decomposition of the next particle of water, *B*, unites with its oxygen atom, and, again forming water, sets the next hydrogen atom free; and so on through the whole chain of electrical action, up to the last particle of water, *D*, at the negative wire, *N*, where an atom of hydrogen, *H*, is finally dismissed altogether in yielding up its positive electricity to the negative wire. We may easily conceive a series of decompositions and recompositions converse to this, from *N* toward *P*, thereby causing a mutual interchange of opposite electricities and a final evolution of the two gases at the opposite wires, *P*, *N*, by the continued action upon successive particles of water in contact with them.

Faraday called these migrating atoms *ions*, and gave the name

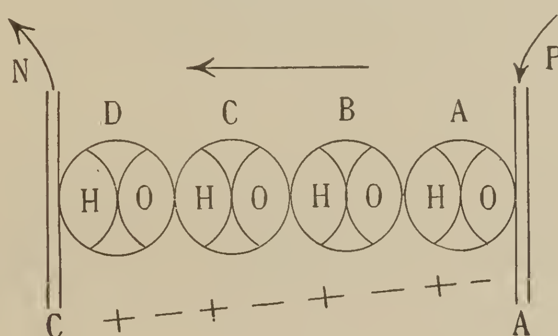


FIG. 66.

anode to the positive plate and *cathode* to the negative plate. Then the ions which went to the anode were termed *anions*, and those which appeared at the cathode *cations*. Two years after Faraday had made his discoveries, De la Rue observed the singular fact that in a peculiar form of Daniell battery the copper plate became covered with a coating of metallic copper, which took the exact impress of the plate, even to the fine scratches upon it. In 1837 Dr. Golding Bird decomposed the chlorides of sodium, potassium, and ammonium, and deposited their respective metals on a negative pole of mercury, thus obtaining their amalgams. This opened up the great industries of electrotyping, electroplating, etc.

Medical Batteries.

Requirements.—The batteries for medical purposes should supply a constant continuous current, and should admit of the elements being joined and used in any desired order. Then the inactive elements should consume no material, and finally all noxious fumes should be avoided.

Before we proceed to the description of the batteries themselves, we will describe an apparatus by means of which any number of elements may be inserted and removed from the circuit. Such an apparatus is shown in Fig. 67. The elements are joined in series, and from each connecting wire another wire leads to the metal strips 0 to 10. The clamp, *D*, is movable along the metal bar, *C*. The binding-screw *A* is connected with the metal strip 0, and the binding-screw *B* with *C*. By moving *D* the elements may be inserted and put out of circuit. This is a very simple apparatus, and is only a specimen of the many different types that are manufactured by surgical-instrument makers. Every electric-battery company or firm have some special contrivance attached to their batteries or separate. So we have a large variety to choose from.

We find it of the utmost importance to recommend a good battery to medical men. This is a hard task. Nevertheless, we shall try and place here, before their notice, such batteries as will answer all the purposes for which they could possibly be required; at the same

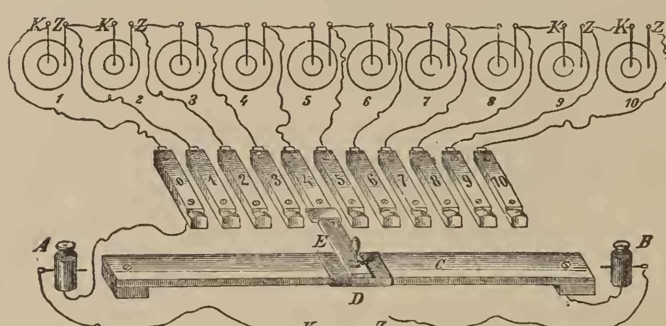


FIG. 67.—APPARATUS FOR COUPLING ELEMENTS.

time be portable and cheap, and not require constant and frequent attention. It is very difficult as yet to combine all these properties in one battery. If many patients are treated, it will be found that two or even more separate outfits will be required. Where, however, it is possible, bring your patient to the battery rather than carry about a portable one; where it is not possible, the question of a portable battery must be made the first object. All kinds of small and portable batteries are to be had on the market; they have them from 10 to 60 cells, arranged in cases fitted with commutators, current-collectors, galvanometers, etc. A few of these, which bear a reputation from their practical usage, are illustrated and described.

The Waite & Bartlett plug-and-socket battery has a wide field of usefulness.

A very respectable reputation is borne by the chloride-of-silver dry-cell batteries as practical, portable apparatuses. They differ essentially from all others, obsolete as well as yet-existent forms, in not only

the particular way and manner the silver chloride itself is applied to electrical work,—insuring compactness, efficiency, constancy, and durability,—but also the fact that the cells themselves, dry and free from liquid, are always ready for use without further attention until their elements are completely reduced and exhausted.

A 50-cell galvanic battery that has an electro-motive force of more than 50 volts, with electrode-cords, rheostat, tray, and mahogany case 6 x 7 x 10 inches, weighs eleven pounds. From a point of cleanliness we

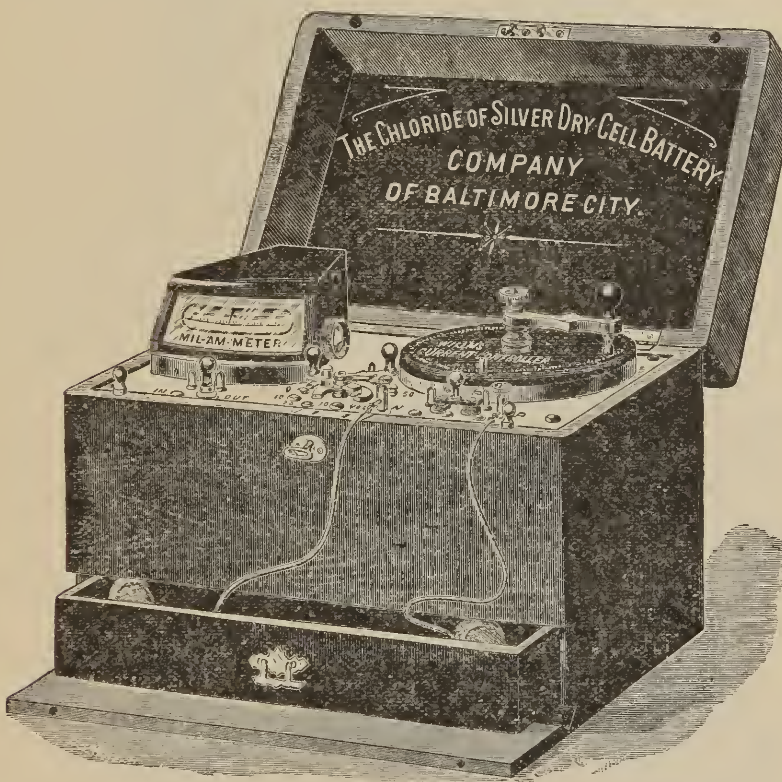


FIG. 68.—FIFTY-CELL SILVER-CHLORIDE GALVANIC BATTERY.

find that, from the absence of all liquid and the hermetical sealing of the cells, this battery must remain in that state. These cells give a constant and uniform current. Steady work does not weaken their strength of current. These batteries are made from 6 to 50 cells or more. Each instrument consists of a number of chloride-of-silver dry cells, hermetically sealed, arranged in series, and encased in a japanned metallic box to themselves, leaving nothing exposed but the connecting pins and nuts securing them to the box-top, as shown in Fig. 69, which represents the inner, removable, cell-case of a constant-current galvanic battery.

When the elements are exhausted this metal case with contents is the part which is renewed,—a matter of mere exchange of one set of elements for another; so simple that no time is lost and labor greatly

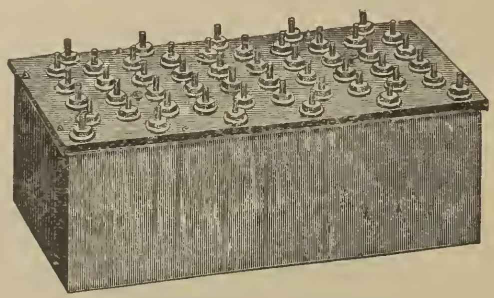


FIG. 69.

economized thereby. The cost of renewal is but 30 cents for each galvanic cell.

These inner cell-cases are now placed in hard-wood finished and polished outer battery-boxes, from which they can be readily removed at any time by lifting-studs; and are finally covered by loose, hard-

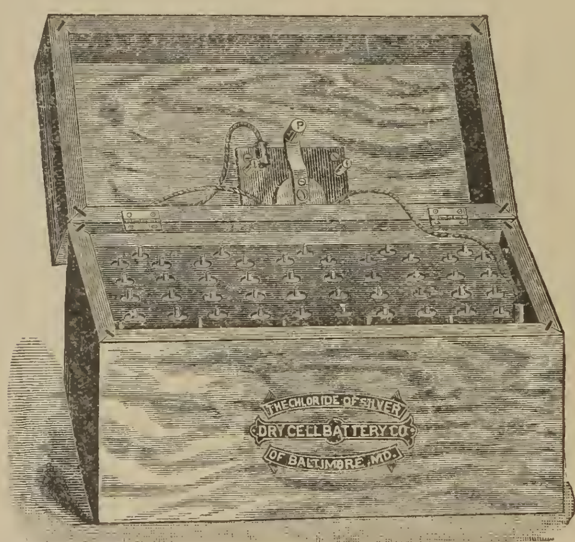


FIG. 70.

rubber plates, through which the connecting pins themselves alone project. Each of these top plates is regularly numbered from 0 up to total number of cells in the battery. Fig. 70 shows the complete battery as described; box open, ready for work.

Leiter's Battery.—Leiter's movable manganese-ore battery is said

to be cheap, to give a sufficient, strong, and constant current, and to be easily managed. One of the elements is shown in Fig. 71.

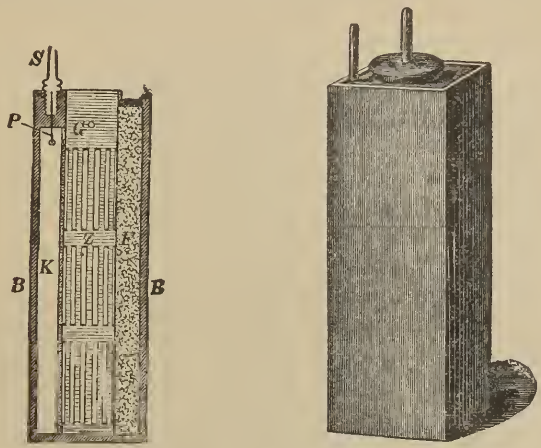


FIG. 71.—COMPLETE CELL.

The cell, *B B*, is made of gutta-percha, and contains a gutta-percha cylinder, *G Z*, which holds the zinc rod. *K* is the carbon block; the

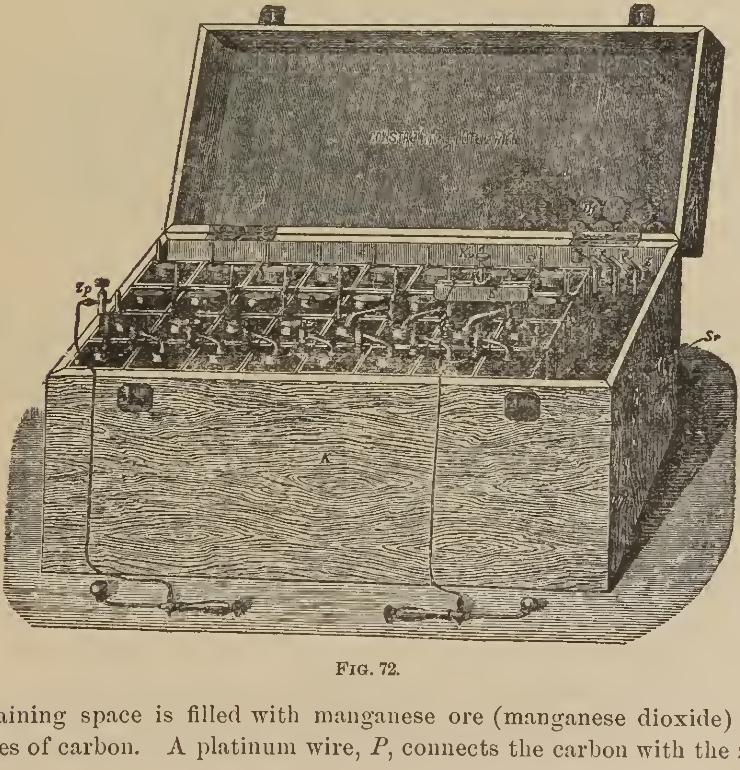


FIG. 72.

remaining space is filled with manganese ore (manganese dioxide) and pieces of carbon. A platinum wire, *P*, connects the carbon with the zinc

piece, *S*, which represents one of the poles of the element. A solution of sal ammoniac is used. The manganese ore and carbon pieces are separated from each other by a layer of asphalt. A number of elements joined up to form a battery are shown in Fig. 72.

The J. Kidder Manufacturing Company makes also a very suitable portable galvanic apparatus. This, like others, has several things to recommend it: The patent, improved attachments for electing various cells without interrupting the circuit when the slide is moved. This is an important factor in some cases. By moving one of the levers, the current is alternately closed and interrupted. Also, the current can be

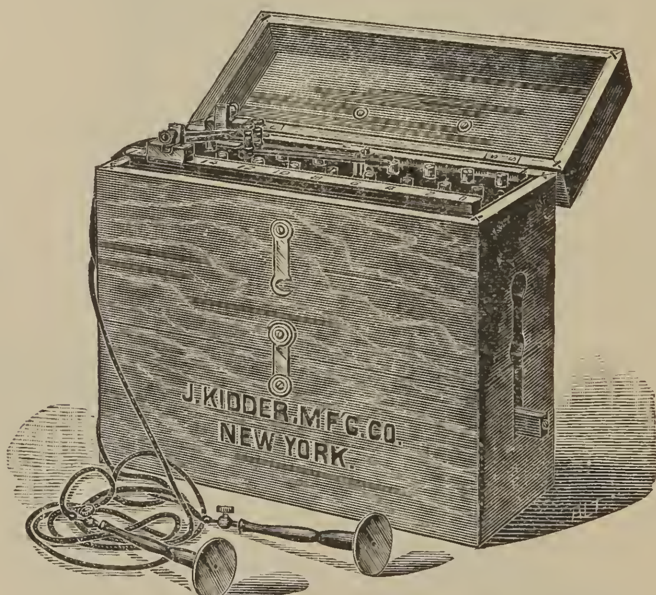


FIG. 73.—KIDDER PORTABLE BATTERY.

thrown rapidly and alternately in opposite directions. Fig. 73 shows the complete Kidder portable battery; Fig. 74, the cell arrangement.

The McIntosh portable galvanic battery has been in the service of the profession for a number of years, and has proved itself sufficiently valuable to merit consideration in this work. This battery is constructed on an improved plan. The zinc and carbon plates are arranged in couples and securely clamped to hard-rubber plates with thumb-screws. Thus any of the couples can be removed by simply loosening a screw. The thumb-screws are also used for binding-posts. By this manner of connecting, the plates are brought nearer together than in any other battery, thus giving less internal resistance. The cells are made in sections of six and a drip-cup composed of one solid piece of hard rubber. By this arrangement one section can be handled, emptied, and cleaned

as easily and quickly as one cell. It also prevents the liquid from running between the cells, as is the case when single cells are used, and danger of breaking, as is the case with glass cells. The drip-

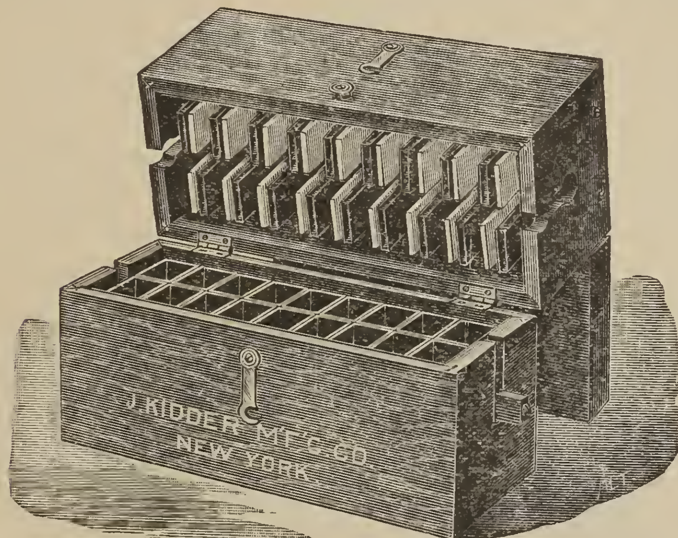


FIG. 74.—CELL ARRANGEMENT.

cup on the side of each section of cells is to receive the zinc and carbon plates when removed from the cells.

Fig. 75 shows the hard-rubber plate of a section (on the under surface of which is cemented a sheet of soft, vulcanized rubber) and binding-posts which project through the hard and soft rubber and screw into the

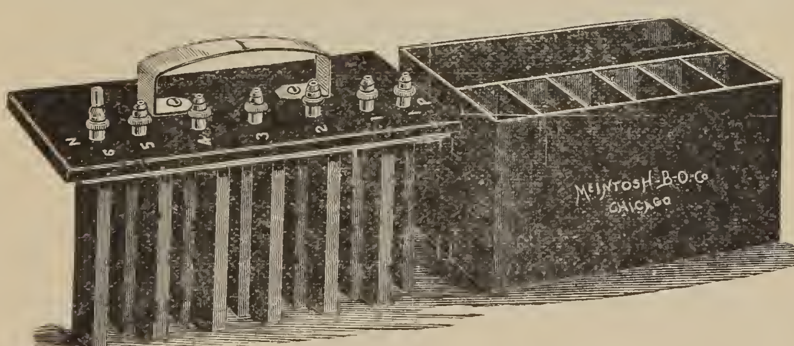


FIG. 75. FIG. 76.

brass piece holding the zinc and carbon couples. The rubber plate on which the couples are clamped projects over on one side enough to cover the cells when the zinc and carbon plates are placed in the drip-cups. When the cells are not in use, and the lid of the battery-box is closed, it

presses on the spring-handle of the section (Fig. 75) and holds the soft rubber firmly over the cells and drip-cup. By this arrangement the hydrostat is made water-tight.

Fig. 76 shows a section of 6 cells and a drip-cup made of one piece of hard, vulcanized rubber. The drip-cup is to receive the zinc and carbon couples when not in use. By the aid of a simple current-selector any number of cells can be used. (See cut.) They are made from 6 to 24 cells.

Enough has been said regarding portable apparatuses. The specimens described and illustrated are only a few of the good ones, and sufficiently enough to select from.

STATIONARY AND CABINET-STAND APPARATUSES AND BATTERIES.

When portability is not taken into consideration the difficulties in settling upon the choice of an electric appliance are greatly lessened, for 60 large cells suitably arranged will give off sufficient current-power for all electro-therapeutic purposes. When we arrange our cells to give the best effects in any given case we must not lose sight of the fact regarding their internal resistance. As to the giving of any exact figures as to the internal resistance of various batteries, I have already roughly stated it in the pages devoted to the study of batteries. That of a Daniell cell should not much exceed 1 ohm; a "sawdust" Daniell may have 10 or more ohms; a Leclanché cell may have a resistance of from 1 to 5 ohms. If any one wish to inquire into the practical and the detailed accounts of the measure currents of the resistance and electro-motive force of batteries with sufficient accuracy for this method, they will be found and described in "Practical Physics," by Glazebrook and Shaw; in the "Text-Books of Science" series; or in "Practical Physics," vol. ii, by Balfour Stewart and Gee. However, it is of importance to have some knowledge of the resistance of the battery in order to know whether, for any purpose, it is best to arrange the cells that are to band in series or in parallel. Of this something has also been said in the foregoing pages.

Let us continue what we intended saying further about stationary batteries. It is found that, as a rule, for a fixed installation for galvanic and faradic work 60 large Leclanché cells are fitted up, and these are convenient, as they require little attention and remain in good order for long periods. These cells will be of sufficient power for electrolysis, etc. For other therapeutic effects, as the electric bath, cautery, and lighting purposes, the other apparatuses already spoken of are required.

There are many very fine cabinets and stationary mechanisms sold, for use in all kinds of electro-therapeutical applications. A few of the best ones are described and illustrated.

A very fine and complete stationary cabinet-stand battery is the one shown (Fig. 77); it is made by the J. Kidder Manufacturing Company. It has a compound circle switch for electing without shock, singly,

any number of cells in the series, or for cutting out cells as desired. Also, to elect any number of cells in any part of the series. There is a current-reverser for reversing the poles of the galvanic current; also an automatic interrupter for rapidly or slowly breaking the galvanic current. This is operated by an independent battery, and so arranged as not to short-circuit the galvanic cells. A small switch controls the operation of the automatic interrupter. There are, in addition, a centre-bearing switch for the control of the galvanic current, and a circuit button. By simply raising the screw the current of any of the galvanic combinations is instantly cut off. A galvanoscope and cord-posts finish

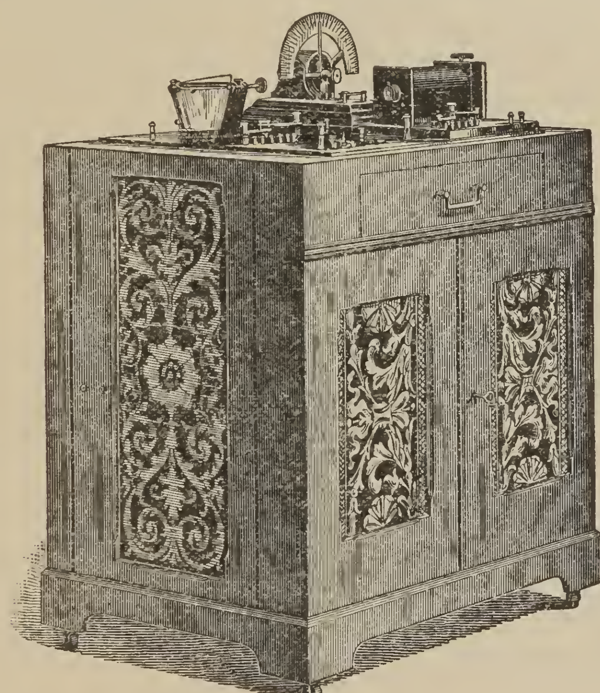


FIG. 77.—KIDDER CABINET BATTERY.

a more perfect arrangement. The faradic coil produces ten different combinations of currents. A circle switch for electing any of the various faradic combinations, a current-reverser for reversing the poles of the faradic currents, a centre-bearing switch for controlling the faradic currents, a small switch for operating the faradic coil with one or more batteries, and a vibrating device for the faradic coil are also added. When current-reversers are moved toward the left the positive pole is left-hand cord-post. Toward the right the positive is right-hand cord-post.

New Induction Coil.—In utilizing these currents of high tension and

large quantity, it is absolutely essential that we be able to increase them by almost imperceptible gradations from zero to the maximum strength required. In what are termed the separate-coil apparatus (wound for high-tension currents) this is readily accomplished by a stationary primary coil, over which are glided at will helices composed of wire of varying thickness and length. The continuous-coil apparatus, as ordinarily constructed, comprised in a single compact helix all the merits of the separate-coil apparatus with its various and cumbersome helices, with the single exception of an inability in the beginning to yield a sufficiently slight current, especially when the so-called quantity currents were used internally by the bipolar method. In the device (Fig. 78) suggested by Dr. A. D. Rockwell, and made by the Kidder Manufacturing Company, this difficulty has been successfully overcome by having a permanently-fixed helix, *A*, with a movable primary coil, *B*.

The total length of the coil of this helix is 7552 feet, with the following subdivisions: 696 feet of No. 21 wire, tapped at 116 and 580 feet; 2116 feet of No. 32 wire, tapped at 783 and 1335 feet; 4740 feet of No. 36 wire, tapped at 1740 and 3000 feet. The heavy coil of No. 16 wire

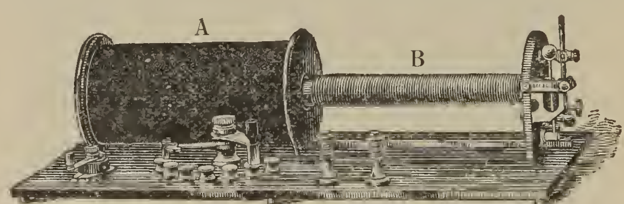


FIG. 78.—THE ROCKWELL COIL FOR CURRENTS OF QUANTITY AND TENSION.

has been discarded and the No. 21 coil so arranged as to yield a current equal to No. 16. The merit of this arrangement consists of one's ability to use the whole 7000 feet and more of wire, or to utilize, at will, each section of the coil with its subdivisions far more readily than when they are wound on separate spools, and at the same time to increase the current-strength by imperceptible gradations from zero to the maximum. So high is the resistance offered by the great length of wire in such a helix as this that a comparatively large electro-motive force is necessary to run it. Almost any form of cell can be used.

If any one of the sal ammoniac cells be used, it is a good idea to combine them in multiple arcs of two each. In this way polarization takes place much less rapidly than when they are connected in simple series, and six cells are sufficient for any strength of current desired.

It is this insusceptibility of low resisting tissues to currents of exceedingly high tension that renders this quality of current of so much value for the relief of pelvic pains of a non-inflammatory character, while the extraordinary readiness with which currents of large quantity and low tension affect these same tissues gives to them a special value in certain nutritional disturbances.

The upright cabinet made by the Galvano-Faradic Manufacturing Company is one of the finest specimens of workmanship, and is complete in every detail. It is furnished with forty or more cells of the Fitch perfect battery, which is unquestionably the best ever devised for electro-therapeutic work. The galvanic circles, with double cell-selectors, wire-coil rheostat, pole-changer, automatic rheotome, and the various switches to bring into circuit the milliammeter, automatic rheotome, and water rheostat, are mounted on a vertical base, and the faradic coils, water rheostat, and binding-posts are placed on a horizontal base of polished hard rubber, all parts being handsomely nickel-plated. The cells are arranged on shelves in the lower part of the cabinet, doors being provided so that they are easy of access. Heavy, insulated copper wires connect the cells with the buttons within the circles on the base, the wires passing up at the back of the cabinet, which may be opened and expose the connections to view. The double cell-selectors allow the operator to select any cell or cells within the circles, and to use them uniformly.

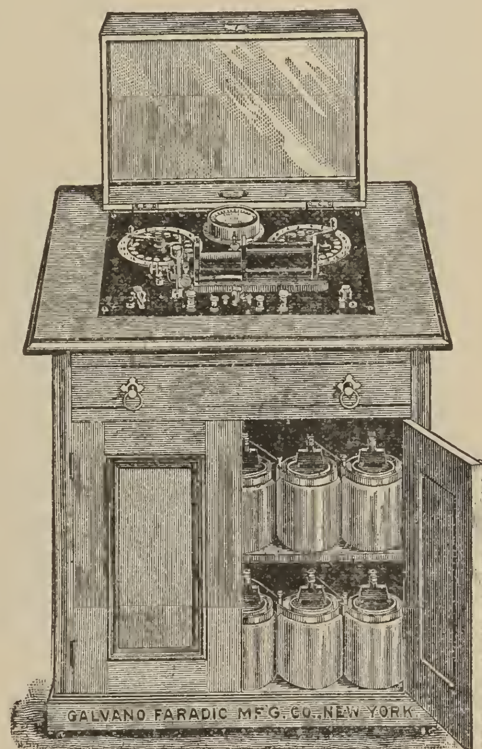


FIG. 79.

They are provided with broad-flange bottoms, and, when selecting additional cells, these slide from one button to another, always resting on one before leaving the other, so that a gradual increase of the current is insured without the possibility of a shock. The rheostat has German-silver-wire coils of from 5 to 5000 ohms resistance, a total resistance of 17,000 ohms, and may be used, in connection with the meter, to measure the resistance of the patient or to test the condition of the cells. The meter is a vertical form, which is unaffected by magnetic influences and, therefore, does not have to be adjusted. It has a scale of double values, and measures from 1 to 500 milliampères. This is placed on a bracket in the top of the cabinet, and is easily read from a distance. The

automatic rheotome gives graduated interruptions of the galvanic current. It is constructed on the principle of a clock, and is operated by a strong spring that is not liable to get out of order.

The water rheostat may be used to gradually modify the current from any series of cells. The faradic apparatus is of superior construction, and differs materially from those in common use. This consists of two parallel primary coils, to one of which a slow vibrator is adjusted, and to the other an improved form of rapid vibrator or rheotome, which is a thin metal ribbon, fastened permanently at one end and at the other attached to a screw-lever, by means of which the tension of the ribbon may be varied and the maximum number of vibrations attained, producing the most sedative effect. The Goelet system of interchangeable secondary spools are furnished, these being wound with different sizes of wire and tapped at different lengths, giving effects from seven coils. The fine coil has 1500 yards of No. 36 wire, tapped at 500 and 1000 yards; the intermediate coil has 800 yards of No. 32 wire, tapped at 300 and 500 yards; and the coarse coil has 250 yards of No. 22 wire. The coils are operated with four extra cells connected in series with a circular wire rheostat which regulates the strength of the current.

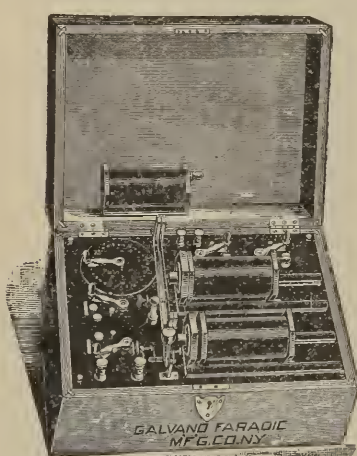


FIG. 80.

The cabinet is made of oak, carved and beautifully finished, has beveled plate-glass doors, and the inside fitted with beveled plate-glass mirrors. It also contains two large drawers in which a complete set of electrodes are tastefully arranged. The cabinet is mounted on rubber-tired wheels, making it easy to move over a carpet or a polished floor without marring.

Fig. 79 illustrates a convenient and desirable form of office battery, made by the Galvano-Faradic Manufacturing Company, of New York, for a physician in moderate circumstances. This battery is square in form, 37 inches high, 27 inches wide, and 23 inches deep. The current is supplied from forty cells of the Fitch perfect battery.

The switch-board contains the galvanic circles with double cell-selectors, milliammeter, du Bois-Reymond faradic coil, pole-changer, and other necessary switches.

This method of controlling the current obviates the use of a rheostat and also admits of the selection of any cell or series of cells and uniform use of the same.

The meter is direct reading, and measures from 1 to 250 milliampères. The faradic coil has a sliding secondary coil wound with 1000 yards of No. 32 copper wire, which is tapped at 500 yards, giving the effect of two coils, one of 500 yards and one of 1000 yards in length. It is fitted with a rheotome, giving rapid interruptions, and a slow vibrator, by means of which the interruptions may be graduated.

The advantage of the combination of secondary induction coils known as the Goelet faradic battery (Fig. 80), and manufactured by the Galvano-Faradic Manufacturing Company, is that the variations of the current to be derived therefrom render it universally useful in applying this agent (in this form) to a greater variety of conditions than was ever possible with the old forms of faradic apparatus.

To appreciate the qualities of the induced (faradic) current the fact

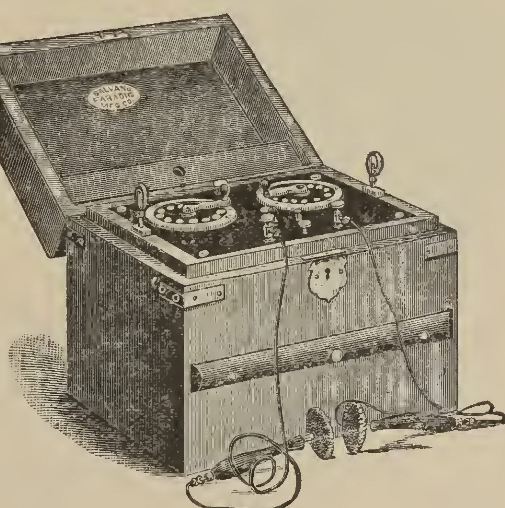


FIG. 81.

must be borne in mind that the character of this current is varied both by the number of turns or convolutions of the wire in the secondary coil surrounding the primary or core, whence the current is derived by inductive influence, and also by the greater or less resistance offered the current by the coil itself,—this resistance being greater the longer and finer the wire, and less the shorter and coarser the wire. That is, upon the variation of the two qualities, electro-motive force and volume, depends the difference in its character and its therapeutic properties. The vibrator or rheotome is of novel construction, and is an important feature of this battery. This is a thin metal ribbon, fastened permanently at one end and at the other attached to a screw-lever, by means of which the tension of the ribbon may be varied and the maximum number of vibrations attained, which is absolutely necessary to accom-

plish the object in view. This arrangement permits a wide range of variation in the number of interruptions per second.

Fig. 81 illustrates a portable galvanic battery of twenty-four cells made by the Galvano-Faradic Manufacturing Company. In the bottom of the box is a movable tray in which the cells are placed. This tray is controlled by two hinged rods which are fastened to it, and these by two lifting-rings at the ends of the rubber table. These rings, being screwed tightly down, hold the cells firmly against the hydrostat, or, being loosened, allow the hydrostat to be removed from the front of the centre of the box; they also serve as handles to lift the tray of cells.

The zinc and carbon plates are arranged in couples and fastened to a base under the rubber table. Wires connect the elements with the

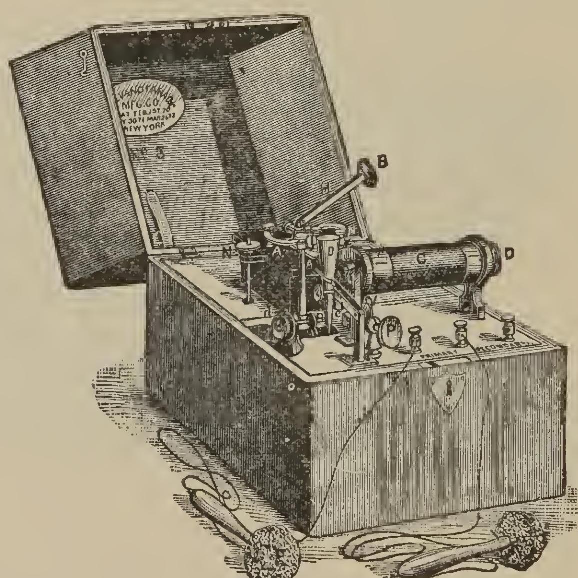


FIG. 82.

button within the circles on the rubber table, each button corresponding to a cell. These wire connections being incased, the fumes from the fluid cannot reach them; *consequently, no corrosion can take place, and the battery is always ready for use.* To use the battery, the hydrostat is drawn out and the tray of cells raised, thus immersing the elements in the fluid. To bring any required number of cells into the circuit the current-selectors are turned to the figures marked on the circles. The battery is provided with a commutator or polarity changer.

The Galvano-Faradic Manufacturing Company's No. 3 battery, shown in Fig. 82, is an excellent instrument. It has a large coil, gives three variations of the current, and has both rapid and slow vibrators, the latter being valuable in producing muscular contractions.

This can be regulated so as to give slow and distinct shocks, as well as quick vibrations, at the will of the operator.

The electrical cabinet shown on next page is one of the Chloride-of-Silver Dry-Cell Battery Company's. It is provided with 100 chloride-of-silver cells, which are capable of easily yielding a current large enough for any case in medical practice. These cells are connected up to a series of blocks in a switch, in ten sets of 10 cells each. By moving the switch, therefore, it is possible to throw in circuit 10, 20, 30, 40, 50, 60, 70, 80, 90, or 100 cells, as well as to select any set or sets of 10 cells which may be desired. This is sometimes a great advantage, inasmuch as needlessly-large resistances in the circuit for regulating the current are by its means rendered unnecessary. From this switch, which may be called the cell-selecting switch, the current is led to a reversing key, thence to a water rheostat, thence through the mil-am-meter, and finally to the main binding-post, to which the circuit cords or electrodes may be attached. Above the reversing key is another similar key, which is used for the purpose of sending into the external circuit—*i.e.*, through the patient—either a continuous (galvanic) or an alternating (faradic) current. This is done by simply shifting the key from one side to the other. The faradic current is furnished by a standard induction coil placed in the left of the cabinet; this coil is supplied with an independent battery of about six cells, and furnished with a key by means of which the current may be interrupted periodically or up to the limit of the machine. Toward the back of the cabinet, but within full view of the operator, is situated a mil-ammeter, also provided with a switch for the purpose of throwing the meter into circuit or out of circuit, as desired. This meter is furnished with three scales, reading respectively from 0 to 5, from 0 to 25, and from 0 to 250 milliampères, and by turning a screw at the side of the meter-case all of these scales may be brought into view successively. According to the work in hand, that particular scale is employed on which the galvanometer gives a convenient deflection. The action of the meter is automatic; so that simultaneously with a change in the scale there occurs the introduction of a *shunt* in the meter circuit, though the external circuit remains always the same.

The Waite and Bartlett Manufacturing Company have given much time to the construction and technical details of their cabinets. The illustration on page 292 shows a complete office arrangement. It contains, for use of constant current, 40 cells of Axo-Leclanché battery. The cells are the most perfect of their kind, and have stood the test of time and use, and are always furnished, unless some other form is specially desired. The current-selector is universal, and any cells, or cell, from the entire series may be used, and thus a great saving of the battery and uniform wear of same are obtained. It contains also an automatic rheotome for giving interrupted galvanic currents. The pole-changer, or commutator, is of substantial make, has rubbing

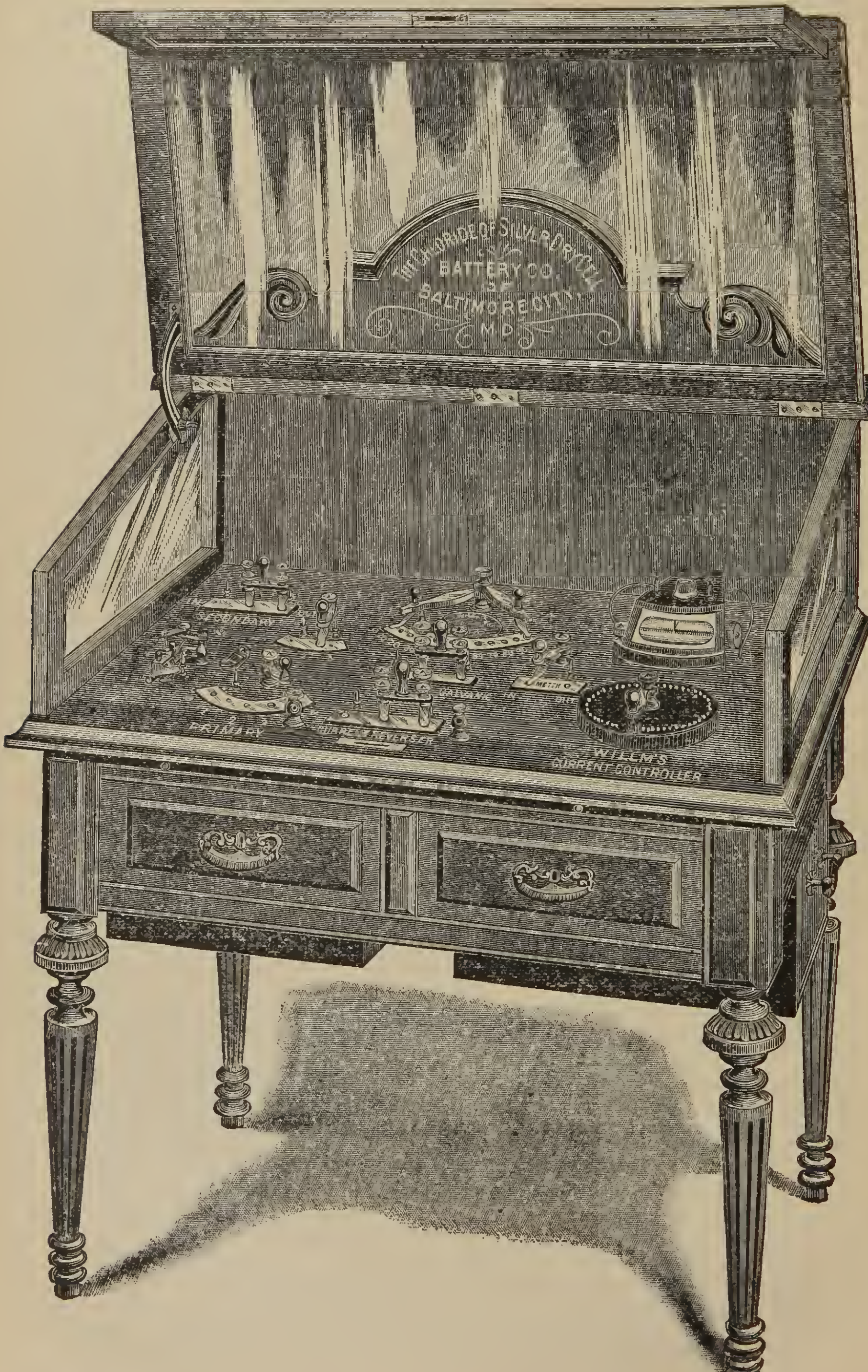


FIG. 83.—ELECTRICAL CABINET PROVIDED WITH CHLORIDE-OF-SILVER DRY CELLS.

contacts, and keeps in order. The German-silver-wire rheostat has coils from 5 ohms to 5000 ohms resistance each, the entire resistance of all the coils being 17,000 ohms, and by means of this rheostat and the milliampèremeter the resistance of the patient's body may be measured or the condition of the cells tested. The water rheostat is used to modify the current gradually. This cabinet also includes the du Bois-Reymond style of faradic apparatus. The secondary coil can be removed, and coils of various sizes and lengths of wire may be used, and the various qualities of current obtained. It is provided with a slow and rapid rheotome, also with a contact-key to be operated by the finger,—a great help in diagnosis. The instrument, also, is furnished with a reliable milliampèremeter for measuring the current-strength. The case contains two small closets with beveled-glass doors, two large drawers, and a sliding shelf available as a desk. The lower part has doors in the back as well as in the front, making the cells accessible and easy of inspection. The total height of the cabinet is 69 inches, length 41 inches, depth 22 inches.

Author's Own Appliance.—The need of an apparatus combining, both in simplicity and usefulness, all the advantages of galvanic and faradic energy led me to devise the table of which I give you an illustration (Fig. 85). The instrument is not yet on the market; it was built for me by Messrs. Waite and Bartlett, from plans and drawings furnished by myself. I have tested the apparatus in every way, and, with my long experience with the many cabinets made for the special use of electro-therapists, of which I have spoken at length in this chapter, laying aside an inventor's pride, I can frankly say that the table is encumbered with fewer disadvantages than any apparatus of its kind that I have yet seen.

It is readily understood in all its workings; and any one with even the most elementary knowledge of electro-physics can thoroughly grasp its most intimate details at a glance. Then, again, it is next nigh impossible to get the apparatus out of working-order.

On the shelves below the stand you will see 44 of the improved Gonda cells, with hard-rubber caps and paraffin coating. Of these 4 are used in the faradic and 40 cells in the galvanic current.

It is equipped, as you will observe, with the recently-devised Engelmann interrupter, by means of which it is possible to obtain from 1 to 100,000 interruptions per minute. Professor Engelmann's coils and interrupter are by far the most useful ones on the market, and the only ones constructed on exact electro-physical and physiological principles.

Only last winter Professor Engelmann, of St. Louis, and myself, assisted by my colleague, Dr. M. Milton Weill, who has devoted years to the study of electro-physiology, demonstrated the action of the interrupter and the coils before a body of the most distinguished electro-therapists in this country. At the time we showed the three distinct physiological effects produced by the interrupter at various degrees of speed.

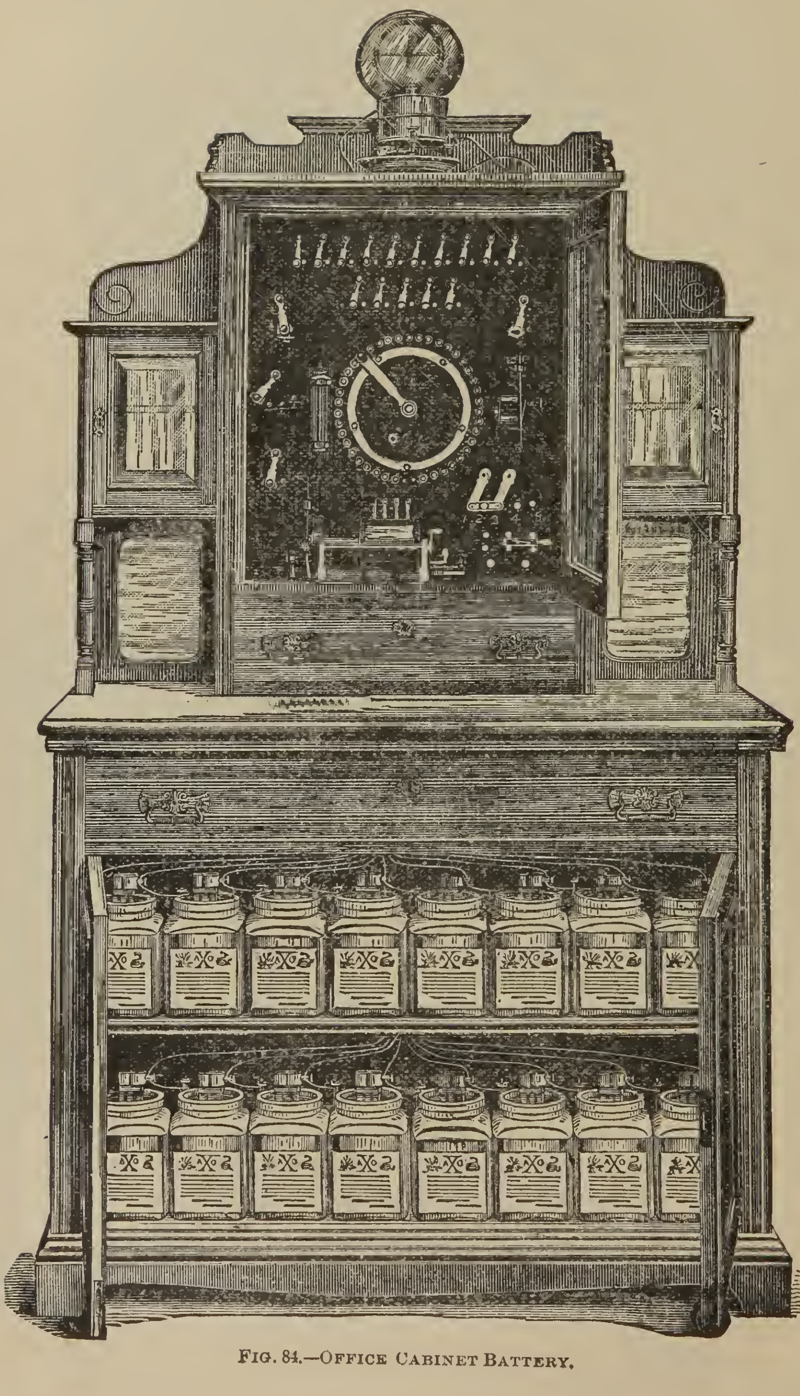


FIG. 84.—OFFICE CABINET BATTERY.

Thus, with from 1 to 6000 interruptions muscular effects alone were experienced ; increasing the interruptions to 18,000 or thereabouts, the muscular responses gave place to nerve stimulation. From 20,000 breaks in the current up to 50,000 or more interruptions, the muscular and nervous effects were lost, and complete cutaneous anæsthesia of the part resulted. The large commutator and the finely-milled-edge wheel record the rate of interruptions, and the speed and number of breaks are readily read from the markings on both wheels.

As you will observe, from the experiments just recorded, we, for the

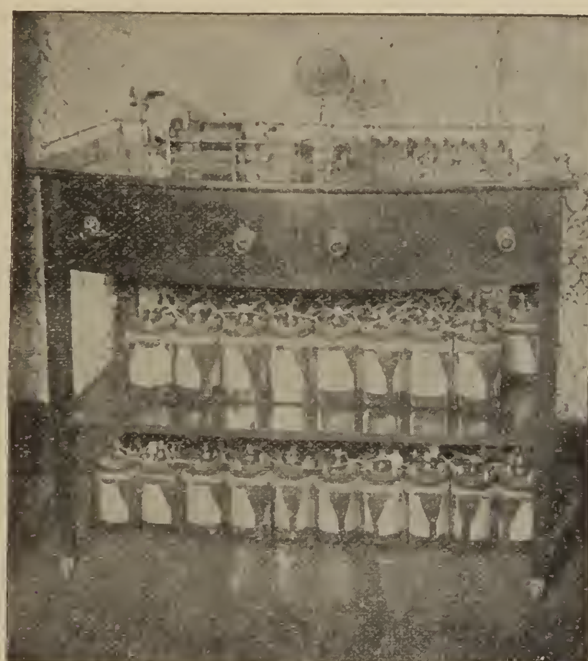


FIG. 85.

first time, find it possible to divide faradism into at least three distinct doses, and place the current under comprehensive control.

I know of no electrical appliance capable of attaining such accuracy. All the interrupters and vibrators—barring none, for I had the good fortune to make comparative tests of a dozen or more of the best ones—have a limit which in no instance exceeds 10,000 interruptions per minute. This is from accurate measurement.

A not less desirable feature of my apparatus is the fact that all the plugs and movable switches—in fact, everything governing the working of the apparatus—are before the operator, spread out upon a table, just as good as the telegrapher's switch-board and instruments are arranged.

The Engelmann coil, too, is constructed with a movable core and bobbin slide, which graduates the rise and fall of the energy of the current as to be least appreciable to the patient; and, so, violent shocks, the disadvantages of which we are aware, are avoided. In other respects the faradic division of the apparatus is built on the most accepted principles.

The galvanic current is governed from the right side of the table. Here we have the pole-changer, the mil-am-meter, and the resistance measuring apparatus, of which I will say a word in explanation. The known resistance of a dozen coils, each governed by a movable shunt, is given. Thus, if the resistance of a patient or a part, as is so essential in thoughtful treatment by means of electrical energy, is to be calculated, the part is placed into the circuit and the current as it flows through is read upon the meter. The rheostat is next thrown in, and the part or patient cut out of the circuit. The known resistance coils are then thrown into the circuit one by one, until the milliampère needle returns to the number it indicated while the patient was in the circuit. Reading off the numbers on the coils and adding them give you the resistance to an ohm. One shunt governs both the galvanic and faradic currents and, besides, the mixed current wherein one pole of the galvanic and one pole of the faradic current are thrown into circuit.

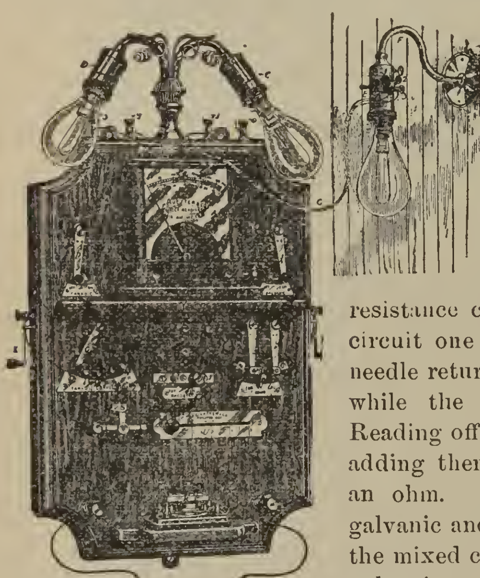


FIG. 86.

There are one or two minor attachments, such as a buzzer or bell to indicate the revolutions of the commutator wheel, which in itself is fitted with movable buckets to further place the faradic current more comprehensively under control, and other improvements which I regard as absolutely essential to a perfect electric apparatus for physicians' use. Of these I shall speak at some future day.

Stationary Apparatus Adapted for either Incandescent or Battery Current.—The above cut shows a wall or table outfit, comprising a complete combination of the latest improved Vetter instruments. An oak base, mounted with milliampèremeter, current-controller, a most complete faradic apparatus, pole-changer, switches, post, etc. This is a good electro-therapeutic outfit for galvanic and faradic and combined galvanic and faradic currents. It is adapted for either the incandescent light or current from batteries.

A very excellent wall and table plate for stationary use is the McIntosh combined semicircle one, of which an illustration is also shown. A full description and the manner of using the plate will be found in the McIntosh catalogue. If one does find room in his surgery for a cabinet, wall cabinets can be made to take the place of the more elaborate and expensive cabinets.

The Incandescent Current—Its Adaptation to the Galvanic and the Faradic, and as Regarding the Charging of Storage Batteries.—Electric light has won for itself an important position among the resources of our civilization; under the rays of science its still-unremedied defects will in time vanish. Each new improvement is gladly hailed and followed

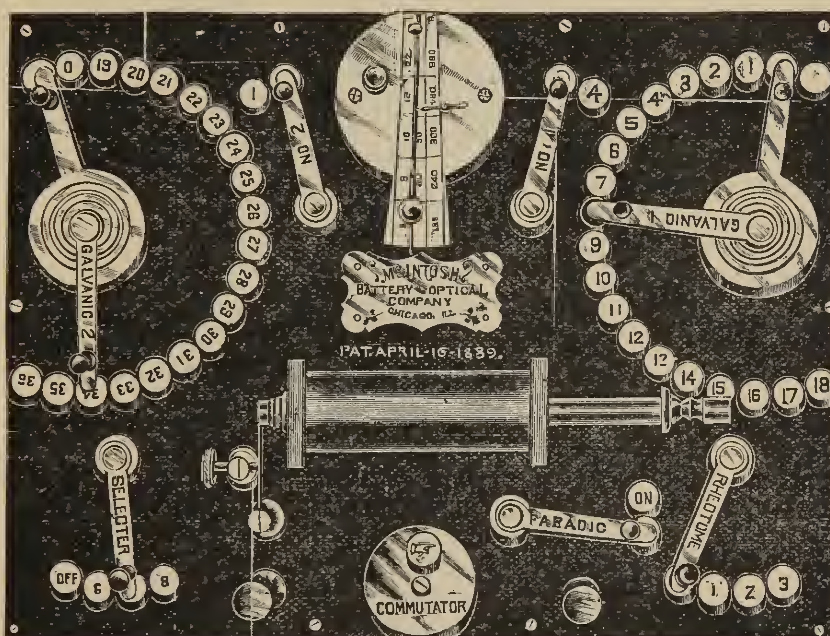


FIG. 87.—McINTOSH WALL AND TABLE PLATE.

immediately by applications that await only the key to open up new paths, and tremendous possibilities for progressive science.

Lighting statistics show that at the present time there are, in the United States, upward of two hundred thousand arc and nearly one million incandescent lamps distributed in over seven hundred cities and towns, not less than twenty million dollars being invested in the business of electric lighting in this country alone.

We find that in medicine also the electric light has been adapted in many ways, and is, even in its present unfinished condition, invaluable in its service.

Of late, several electrical experts have given some attention to the

invention of rheostats for medical purposes, and through these electric light will come into general use among surgeons and electro-therapists. We find already that, in districts supplied with street-currents, specially-designed rheostats promise to be both useful and convenient.

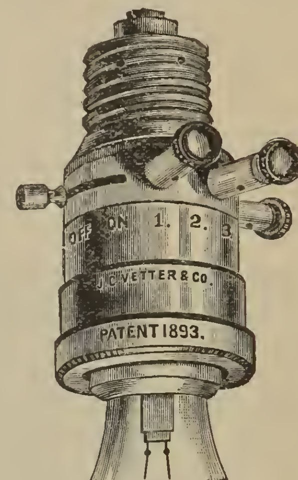


Fig. 88.

The Vetter current-adapter is best suited to various purposes herein to be described, and has given, so far, the most satisfactory proof of practical application. It is simple and compact. It resembles an ordinary incandescent-lamp socket provided with a switch-lever and binding-posts numbered 1, 2, and 3. When connection is made with posts 1 and 2 it gives the current in series with the lamp, the quantity of current passing being regulated by the candle-power of the lamp. When posts 2 and 3 are used the lamp is cut out and the full force of the direct current is obtained. The switch-lever is used only for directing the current from the binding-posts to the lamp.

It does not require the services of an electrician to attach the adapter; any one can do it, even though not familiar with electrical appliances; it is no more trouble to attach or change the adapter from one fixture to another than it is to change a lamp; it is only necessary to detach a lamp from its fixture and place the adapter in its stead, then attach a lamp (of requisite candle-power for the purpose intended) to the adapter, in the same manner as it would be attached to the fixture.

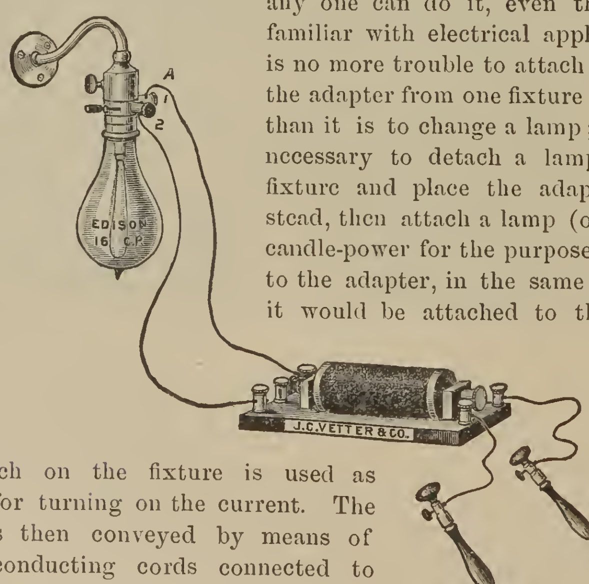


Fig. 89.

The switch on the fixture is used as formerly for turning on the current. The current is then conveyed by means of suitable conducting cords connected to binding-posts marked 1 and 2, or posts marked 2 and 3; posts 1 and 2 giving the current in series with the lamp, and posts 2 and 3 the current in parallel or direct. The switch-lever is for the purpose of lighting the lamp only.

To adapt the incandescent-light current for the operations of various translating devices requiring different ampèrage or quantity currents in their employment, it is only necessary to adjust a lamp of suitable candle-power into the adapter and, by means of conducting cords, convey the current from the binding-posts of the adapter marked 1 and 2 or 2 and 3, as shown in the illustration. (Fig. 88.)

For Faradic Current.—To obtain the faradic current directly from the incandescent current it is only necessary to adjust the Vetter current-adapter to a 16-candle-power lamp and connect posts 1 and 2 to an ordinary faradic induction coil, as shown in Fig. 89. So adjusted, it gives ½ ampère of current, or about the same amount as is given

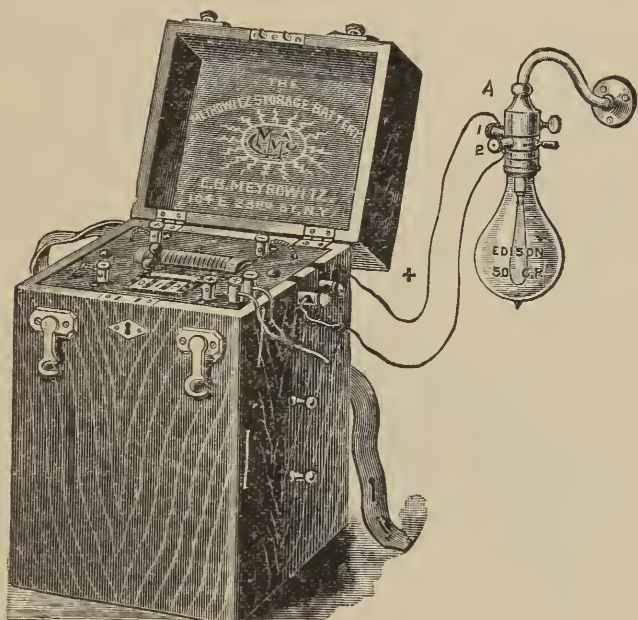


Fig. 90.

by a good battery cell. An ordinary faradic battery can be utilized in this way by connecting the cords from the adapter in place of those from the cell.

For Charging Storage Batteries.—The Vetter current-adapter furnishes a handy and clean method by which storage batteries can be easily and economically recharged, really at no expense whatever if the charging is done at a time when the lamp would ordinarily be in use, as the overflow is sufficient for the purpose. Every practitioner who has had anything to do with the uncleanly and troublesome "blue-stone cells" will understand what a relief this affords.

To recharge storage batteries a 50-candle-power lamp, giving 1½

ampères of current, would be best suited. When the current is in use in series from posts 1 and 2, the lamp in the adapter acts as resistance to the flow, allowing only a limited quantity of the current to pass in that circuit.

For Galvanic Current.—To obtain the galvanic current directly from the incandescent current by means of the current-adapter the conducting cords from posts 1 and 2 are connected to the Vetter current-controller and milliampèremeter, as shown in Fig. 91. The current-controller will in this manner control the incandescent current from 0 to 500 milliampères, which is the greatest amount the 16-candle-power lamp is able to furnish, as a heavier current would break the filament in the lamp and thus stop the current.

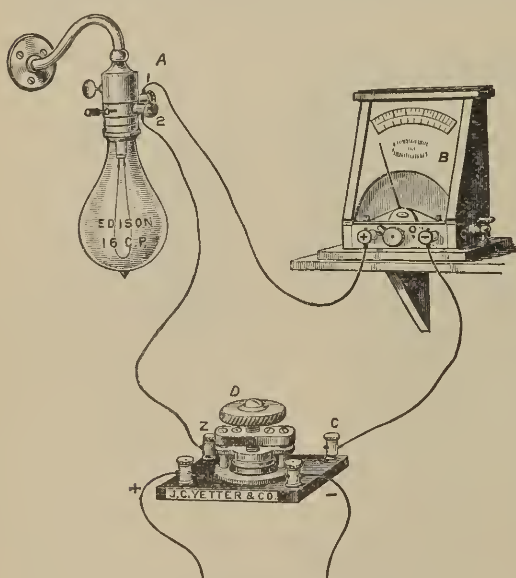


FIG. 91.

Another and perhaps the most perfect combination ever devised for obtaining the galvanic current is herewith illustrated. This illustration (Fig. 92) shows the adapter in connection with the Vetter complete, portable, dry, galvanic battery. This arrangement is especially desirable, as it furnishes the physician with the most perfect outfit for office or hospital, and at the same time a complete portable outfit for outside work. When this apparatus is in connection with the adapter the dry cells are cut out of circuit and are reserved for outside use, making an economical and convenient outfit.

Another new and excellent apparatus to be used in conjunction with the incandescent current is the Gish instrument (Fig. 93). This can be applied for purposes similar to those met by the Vetter current-adapter. This Gish instrument is designed for all galvanic and faradic work, both electro-therapeutic and diagnostic, whether it be in the hands of the general practitioner or the specialist. It also operates the small incandescent lamps used in examining the throat, nose, and internal cavities of the body and electro-magnet. A very important point in using galvanism from this rheostat is that the patients can be treated without giving them any shock whatever, and this one advantage in certain nervous dis-

eases is pre-eminent. Also, the graduation is so fine that the current can be started from zero and give any number or fractional part of milliampères that is required.

There is another form of the Gish instrument (Fig. 94) which is designed for the electro-cautery, and will heat all knives, from the smallest point such as is used in cauterizing corneal ulcers to any electrode requiring 18 ampères of current, and heats the platinum cautery snare. It illuminates incandescent lamps from $3\frac{1}{2}$ volts candle-power upward to the full extent of the current. It also operates the 5-volt motors, adapted

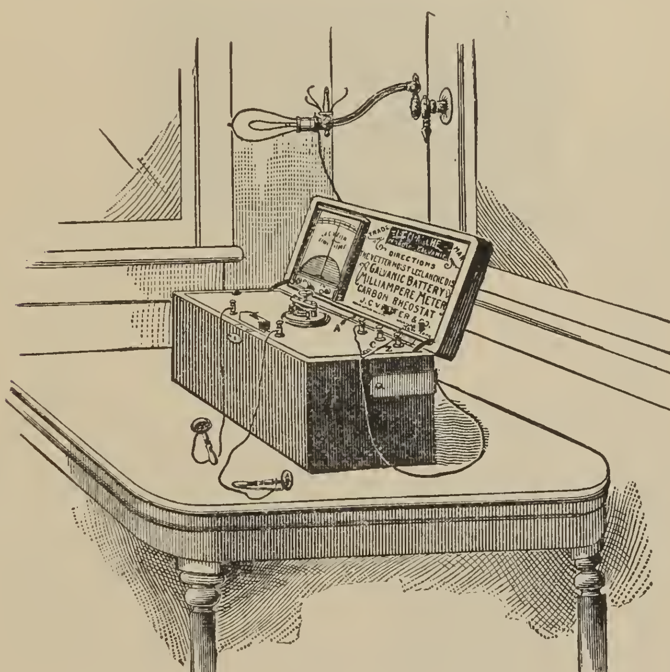


FIG. 92.

to storage batteries, at any desired speed without variation. Special directions accompany each instrument.

McIntosh has lately brought out also an apparatus for use in connection with the incandescent electric light, which is shown in Fig. 95, and a description is given of the mode of operating the same. In order to use this contrivance the following points must be adhered to rigidly :—

Connect the two wires at left side of plate to any Edison current of 120 volts. Be sure and join the wire with knot in it to the *P* of line.

To Get a Galvanic Current at Binding-Posts.—Turn on snap switch in centre of board. Put plug in hole near right-hand lamp and see that the fuse-wire near left-hand lamp is not broken. Fill rheostat bottle with

pure water to within one-half inch of neck part of bottle; place plates in carefully and lower the centre plate with milled screw. Put rheostat switch on the on-button near milliampèremeter and milliampèremeter switch on *A*. Then with cords and suitable electrodes from binding-posts put patient in circuit, lowering your rheostat plate, and watch mil-

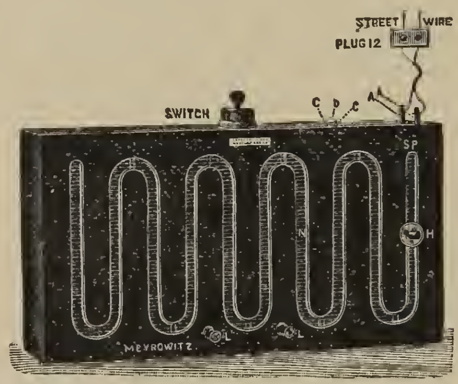


FIG. 93.

liampèremeter until you get the proper strength of current. If you wish to reduce this current still more, turn on the 50-candle-power lamp at right-hand side of board, which is in a shunt circuit with the other lamp. The current at binding-posts on a short circuit with left-hand lamp only is 102 volts and $\frac{2}{5}$ ampère. Now open the 50-candle-power lamp and you

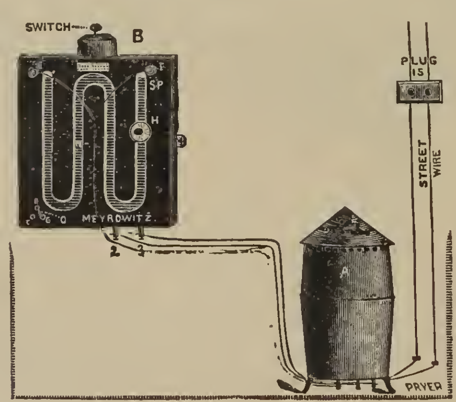


FIG. 94.

get 29 volts and $\frac{7}{20}$ ampère (providing you connect board to Edison main of 120 volts).

To Get a Faradic Current.—Open 50-candle-power lamp. Turn faradic switch near coil on the on-button. Put selector switch on *P* (primary) or *S* (secondary). Place milliampèremeter switch on off.

Keep rheostat switch on the on-button. Touch vibrator on coil to cause it to start and regulate your current with rheostat.

Note.—After through using board turn off snap switch and take out plug near right-hand lamp. Before using turn on snap switch, see that safety switch is not broken, and place in hole the plug cut-out. If the plug cut-out is carried on the person it will insure against children or others meddling with the board.

Caution.—Never use the board without the safety-fuse being in

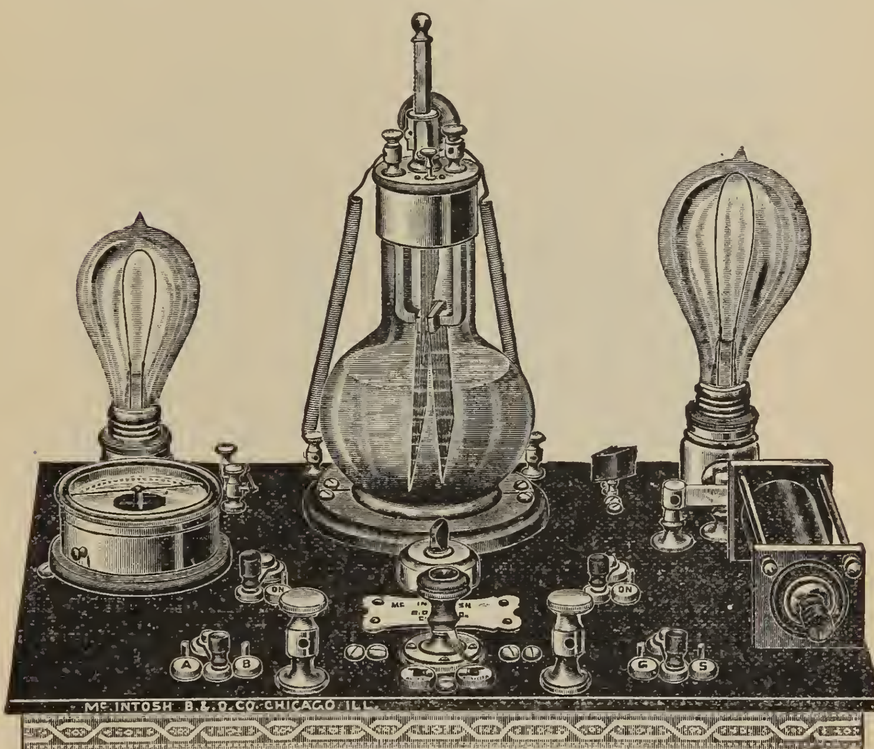


FIG. 95.—THE McINTOSH ELECTRIC-LIGHT SWITCH-BOARD.

place; in case of accident by short circuit or otherwise this safety-fuse will be burned out, and so break the circuit.

There are several other rheostats made by electric-lighting companies, but none so practical for the novice as the ones described. The lighting problem, however, involves many considerations that demand investigation before electric light can become altogether practicable; but we believe that not one of these questions is insoluble, and we hope before long to witness at least a partial transformation in general illumination with the many now possible uses of electricity.

GALVANO-CAUSTIC APPARATUS.

We shall give a description of several batteries which are of great service in particular branches of the medical science, viz., in cauterizing by electricity. For this purpose a heated platinum-wire loop or flat pieces of platinum suffice for cautery knives, loops, etc. Bleeding is almost entirely prevented, and parts most difficult to reach can be operated on, as the heat is more local. Formerly a red-hot iron had to be introduced into the part to be cauterized, but now the platinum wire is inserted while cold, and is made white-hot, or according to the will of the operator, by simply making contact.

Much has been done to advance this branch of medical science by

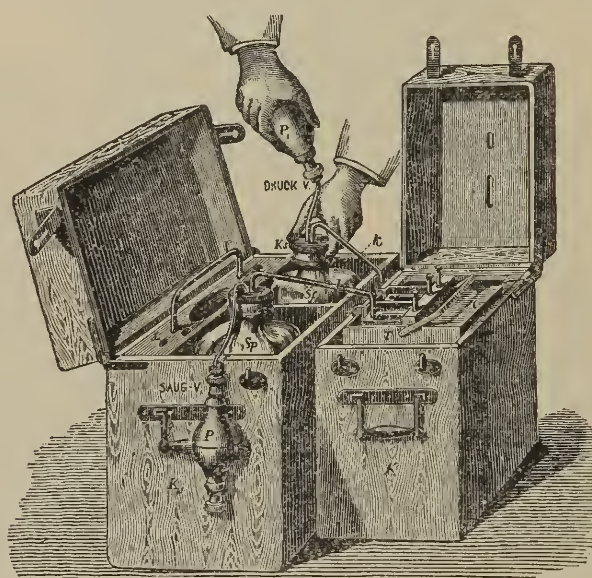


FIG. 96.—LEITER'S GALVANO-CAUTERY.

A. Middeldorf, Recámier and Pravatz, Steinheil, Heider, and others. It will be seen that, as the outer circuit of these batteries is a platinum loop which has only small resistance, it is advantageons to have the inner resistance of the battery also only slight. Hence the battery used has large plates and few elements,—that is to say, the elements are joined up for quantity.

An apparatus constructed by Leiter, of Vienna, for the purpose, is shown in Fig. 96. In its essential parts it is a modified Bunsen battery. The box K contains the battery, and the box K_1 the two acids (sulphuric and nitric). The battery-vessel, T, consists of gutta-percha, and is divided into two portions. In each of these a flat earthenware cell is placed to hold the carbon plate and nitric acid. Outside this dia-

phragm come the zinc plate and dilute sulphuric acid. The elements are covered by means of a gutta-percha lid. The pole-clamps of the battery are screwed to the lid. When only one element is required, clamps 1 and 2 are used; when both elements are required, clamps 1 and 3 are used. The *Sf* is being forced through the bent-glass tube, *K*, by means of the India-rubber balls, *P* and P_1. The acid is removed from the cells by exhausting the acid bottles, and a longer bent-glass tube will then have to dip into the cell. Another form of Leiter's cautery battery is seen in Fig. 97.

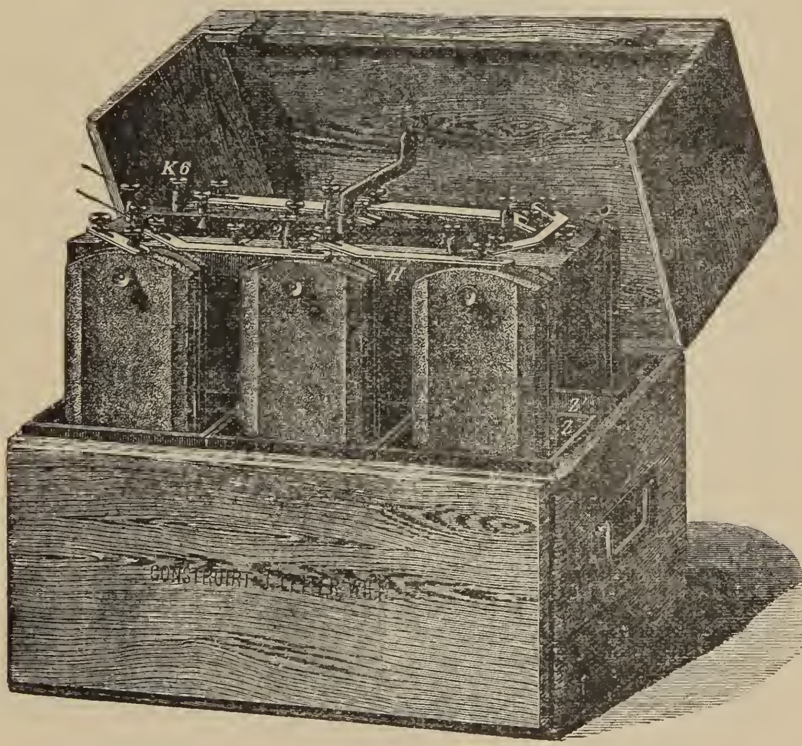


FIG. 97.

We shall also consider the Gibson storage cell, manufactured by W. E. Ford, of New York. A cut of the small portable cautery is shown (Fig. 98). It is put up in hard-rubber or glass jars, with a screw-top cover, hermetically sealed so that the acid cannot spill out, and is inclosed in a polished hard-wood case holding either one or two-cells and a rheostat, and is best adapted to take out to an operation. He also makes other types of cells, which are best adapted to stationary use. Any one of the cells has sufficient power to heat a small cautery knife. Any two of these cells will heat the largest-size knife or loop,

and will light a small lamp. The only difference in the cells is the length of ampère hours they will run, they all having the same electro-motive force.

In my discussion on batteries I have spoken of the Edison-Lalande cell *in extenso*, but I must say a few words regarding these cells for cautery purposes. There are many of them at present in use in the best offices and institutions throughout the United States. This cell has now

FIG. 98.

been brought out by the Edison Manufacturing Company, in a form that renders it peculiarly efficient.

Eight of these cells, each in a rubber case, are placed in an oak box and connected in series by means of nickel-plated straps. The resistance is included in the outfit, and is placed in a very novel manner in the top of the case, on a little hinged lid that can be thrown up so as to expose all the batteries clearly to view. This resistance is in the shape of metallic tape, and operates after the manner of a fishing-reel or ordinary yard-measure. It is pulled out to any length as required, and when the needed resistance is obtained is held at that point. As the

battery falls off, it can be released and rolled up automatically either all at once or gradually.

As is well known, the usual cautery knife requires a considerable volume of current to keep it at white heat—say, 15 or 20 ampères. Of course, in practice the cautery knife is used only a few seconds at a time; the battery therefore would have, with a single charge, a very long life. But, if for any reason it should become necessary to use the knife for an extended period, it may be kept at white heat for eight hours with a

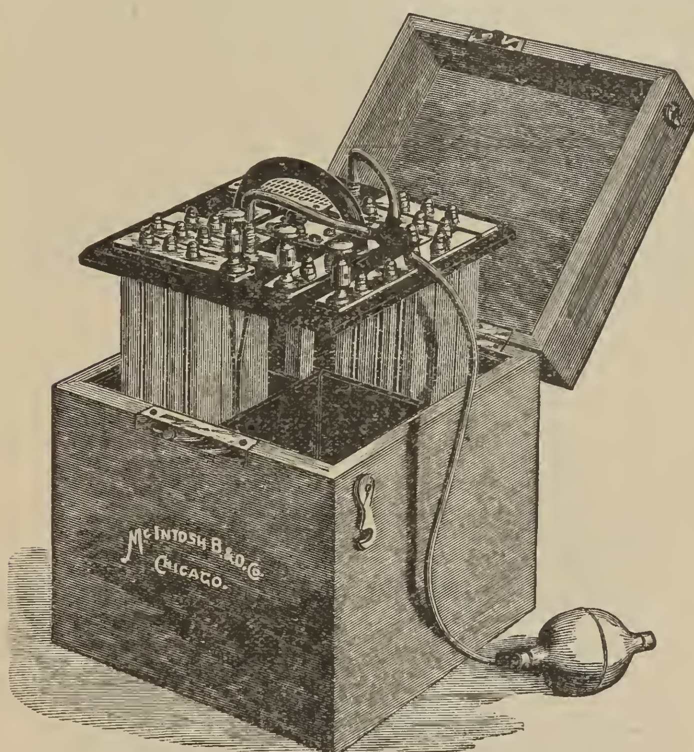


Fig. 99.—McIntosh Portable Galvano-cautery.

single charge, and there will be sufficient current to maintain the ordinary snare at proper heat for many hours.

The McIntosh galvanic cautery is also much in use by many practitioners. This battery is designed expressly for cautery work. It is inclosed in a polished black-walnut case eight and one-half inches long, eight and one-half inches wide, and ten and one-half inches high, and weighs twenty-one pounds. The elements are composed of zinc and platinum, fastened upon a hard-rubber base. They are constructed so as to furnish a very large surface in the smallest possible space, thereby lessening the resistance and increasing the power of the battery. The

cells and drip-cups are made of hard rubber. The base and elements can be fastened at any height by a spring-bolt that slips into slots in a central upright metallic tube; by this means the current can be graduated to any required intensity. This battery is very compact, portable, and can be easily managed by any physician. It is adapted to all cases where galvano-cautery is applicable. (Fig. 99.)

Some of the well-known galvano-cauteries of foreign make are those of Trouvé, of Paris; Mayer and Meltzer, of London; Down Brothers, of London, and Coxeter & Son, London. Besides the galvano-cautery battery in surgery, the Gramm machine was enlisted also into its service. Dr. Hedinger, of Germany, was the first to put it into practice. It is so constructed that it can be run either by hand or motor power. This is a very valuable cautery for stationary purposes and where motor power

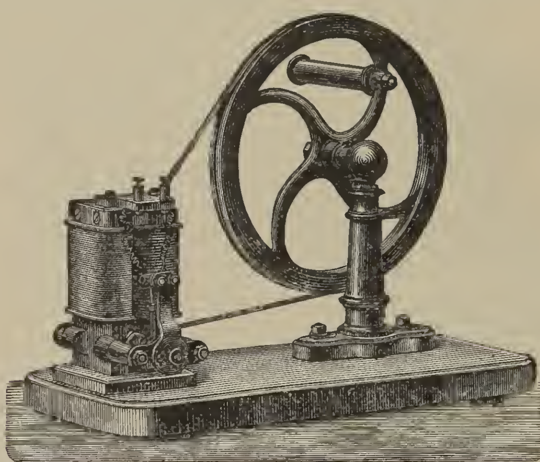


FIG. 100.—THE GRAMM MACHINE FOR CAUTERY USE.

can be had. A description of this Gramm cautery is hardly necessary, as the cut fully describes the machine.

There are other primary and secondary batteries, but the limited space allotted, in a work of this order, does not permit me to dilate further. I have already mentioned other methods of using the cautery, as by the incandescent-light tap and by rheostats..

PORTABLE BATTERIES FOR ELECTRIC LIGHTING.

The science of medicine owes much to the artificial sources of light for means of examining such portions of the body as cannot be directly seen. As instances we may mention the larynx-mirror used by Liston in 1840 and re-introduced by Czermak in 1858, and the eye-mirror with the help of which Helmholtz obtained for the first time a light of the structure of the living eye, etc. As a rule, daylight or a lamp is used

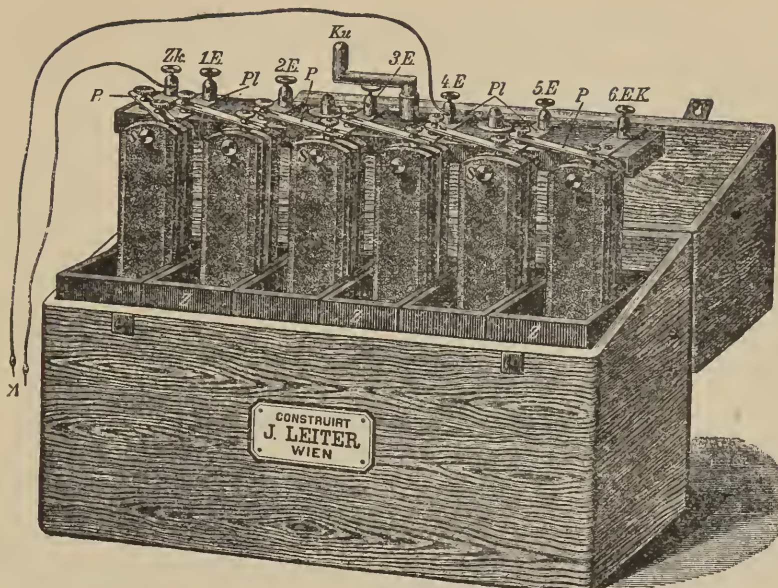


FIG. 101.—LEITER'S PORTABLE LIGHTING BATTERY. (Large size.)

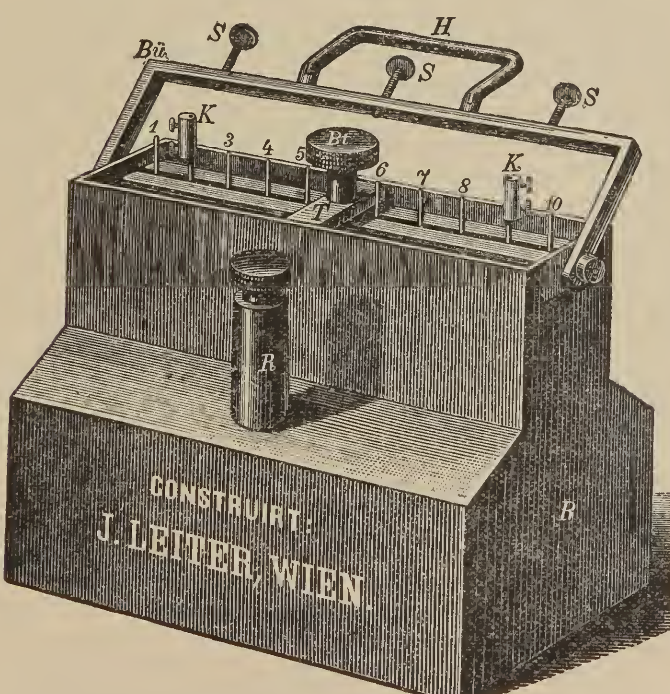


FIG. 102.—LEITER'S PORTABLE LIGHTING BATTERY. (Small size.)

for such examinations, the rays being concentrated by means of a concave mirror; but, as we shall show, the use of a glow light in such cases is extending. A second method in making the body under examination visible is to introduce the source of light itself, and for this purpose the electric light alone can be used.

There are instruments constructed by various surgical manufacturers throughout the world for all kinds of illumination,—within and for without the body. Amongst the first manufacturers is J. Leiter, of Vienna. The different illuminating instruments will be touched upon by my co-editors in their special branches. I only wish to speak upon the portable batteries for illumination. Two of the Leiter portable batteries are shown on preceding page.

BIBLIOGRAPHY.

Henry S. Carhart, A.M.: Primary Batteries, 1891.——A. E. Kennelly and H. D. Wilkins: Practical Notes for Electrical Students, London, 1890.——Park Benjamin, P.H.D.: Age of Electricity, 1889.——Alfred Niaudet: Elementary Treatise on Electric Batteries.——Steavenson and Jones: Medical Electricity.——W. E. Ayrton, F.R.S.: Practical Electricity.——T. O'Connor Sloane, P.H.D.: The Arithmetic of Electricity.——Alfred Ritter, von Urbanitzky: Electricity in the Service of Man.——Fleeming Jenkin: Electricity and Magnetism.——T. C. Mendenhall: A Century of Electricity.——R. E. Day: Electrical Measurements.——James Clerk Maxwell: Treatise on Electricity.

ELECTRO-PHYSIOLOGY.

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Historical Introduction.

One of the most interesting chapters in the history of physiological science is that relating to the origin and development of the electrical phenomena of muscles and nerves. Here, if anywhere, we have a striking illustration of the fact that new discoveries are not always the result of logical thought and a correct interpretation of phenomena. On the contrary, the history of electro-physiology clearly shows that often the new discoveries were dependent upon faulty observations, imperfect deductions, and bitter controversies; for, had Galvani's explanation of the first observed contraction been the correct one, it is quite possible that the phenomenon would have aroused but slight interest, and the development of electricity and physiology would have been retarded for many years.

Luigi Galvani, a professor of anatomy and physiology in Bologna, while making some experiments with a frictional apparatus, had his attention drawn to the fact that a recently-dissected frog's leg was thrown into a violent contraction whenever it was touched with a scalpel held in the hand of his assistant. Further investigations revealed, moreover, that the contractions occurred only when a spark was emitted from the frictional machine, and then only when the metallic substance was in contact with the preparation. Galvani was unable to offer any explanation of this phenomenon, as there was apparently no connection between the electrical machine and the frog's leg, by which the electrical spark could be conducted. The exact time of this observation is not known, but it is quite certain, from the evidence gathered by Prof. du Bois-Reymond ("Untersuchungen über thierische Electricität," Bd. i, S. 31), that it was prior to the year 1786, the date usually given in text-books. It is quite probable, from notes and dates upon the margins of his manuscripts, that Galvani began his investigations as far back as November, 1780. From this period he continued his observations and experiments up to the year 1786, when it occurred to him to determine whether the effects of atmospheric electricity upon the frog's muscles would be the same as that from the frictional apparatus. This supposition was confirmed by a series of experiments made during the year 1786, from the 26th of April to the 17th of August, for every flash of lightning was immediately followed by a contraction of the muscles. While yet occupied with these investigations, another observation was accident-

ally made by Galvani, which became the real starting-point for the development of the new science of electricity; for hitherto his observations had disclosed no new principle, although Galvani himself believed that only a new principle—animal electricity—could account for the phenomena. The effect of the electrical returning-stroke, however, which had been described by Lord Mahon, in 1779, in his "Principles of Electricity," offers, indeed, and was so held by Volta, a sufficient explanation for all the phenomena so far observed. On the evening of September 20, 1786, Galvani prepared and suspended three frogs to the iron trellis-work of his house by means of iron and, subsequently, of copper hooks, and observed that whenever the wind brought them into contact with the iron violent contractions took place. These movements Galvani also, at first, attributed to atmospheric electricity; but when it was afterward observed that the same phenomena occurred independently of variations in the electrical conditions of the atmosphere, and even in closed rooms, he arrived at the conclusion that the metallic arc, composed of either similar or dissimilar metals, was one of the conditions necessary for the production of contractions. That Galvani had, therefore, a true but slight perception of the cause of the contractions in these experiments is evident from the title of his paper, "Esperimenta circa l'Elettricita di metalli." He soon abandoned this view, however, and, from many other experiments, arrived at the conclusion that the electricity was developed within the animal tissues themselves, and that the metallic arc merely conducted the electricity from one part to another. These observations and conclusions were published in 1791, in the celebrated "De viribus Electricitatis in motu musculari commentarius."

With the publication of this paper, the attention of the whole scientific world was directed to Galvani's experiments. They were repeated again and again, wherever frogs were to be found and dissimilar metals procured, by all those who wished to familiarize themselves with these remarkable phenomena. Among the many distinguished men who became interested in this subject there was one who, by a series of delicate electrical experiments with Wilcke's electrophorus and the condenser, had made himself a recognized master in the field of electricity. Alexander Volta, a physicist, and professor of natural philosophy in the University of Pavia, repeated Galvani's experiments, and at first entered fully into the views of his countryman. But his calm and philosophic mind soon observed the important part which the arc played in the production of contractions; for, as he was unable to excite contractions except by a combination of heterogeneous metals, he soon dissented from the interpretation of Galvani, although the latter had already perceived and stated that the contractions were stronger when the arc consisted of two dissimilar metals than when composed of a single homogeneous metal. Volta then endeavored to produce muscular contractions in the tongue by placing on its upper surface a layer of tin-foil and on its under surface a

silver spoon. When the circuit was closed, to his astonishment, he experienced, instead of the expected muscular contraction, a strange sensation of taste, and perceived that this sensation persisted as long as the two metals were in contact with each other and the two surfaces of the tongue. This experiment had been made by Sulzer in 1754, and recorded simply as a curious fact; but to Volta's mind it became a potent argument for his view, that the electricity which produced the contractions was not resident in the animal tissues, but was developed by the contact of two dissimilar metals with moist tissues. Subsequently he proved by physical apparatus that electricity was developed by the contact of two dissimilar metals with a moist conductor, independent of any animal tissue. Sulzer's experiment thus gave birth to voltaic electricity, the greatest discovery of the eighteenth century.

In support of his position Galvani asserted, and apparently demonstrated, that it was possible to excite contractions, though perhaps feeble ones, by contact of homogeneous metals; but Volta replied that, when metals were believed to be perfectly homogeneous, there were on their surfaces slight differences in temperature, hardness, polish, etc., which were sufficient to produce the electricity. Galvani then employed mercury as a metallic conductor, to which he thought the objections of Volta could not apply; by dipping the limb into the mercurial trough contractions at once resulted. To this experiment Volta replied that the surface of mercury was wanting in perfect homogeneity from the contact of air and moisture, and, therefore, capable of developing electricity.

Galvani's position thus seemed to be completely controverted by these experiments. It now remained for him to show that contractions could be produced without the contact of metals at all, and, in 1793, he offered what he believed to be the *experimentum crucis* in support of his theory, and which would establish it upon a firm and enduring basis. The leg of the frog was denuded and the sciatic nerve dissected out and its upper end cut off close to the spine; then, by means of non-conductors and without subjecting the nerve to any influence which could produce change in it, he gently brought its cut end in contact with the muscle. At once a distinct pulsation ensued. Similar pulsations were caused by allowing the nerve to fall upon a piece of abdominal muscle which was lying on a glass plate, and which had no connection with the frog. Galvani had thus apparently proved his case. Volta, however, did not admit his conclusions, and endeavored to refute them by declaring that the contractions so caused were extremely weak in comparison with those caused by the contact of heterogeneous metals, and that they were due to mechanical irritations incidental to the manipulations of the nerve. Subsequently he retracted these statements, and offered as an explanation that the electricity in these experiments was developed from contact of dissimilar fluids and tissues: a view which was readily accepted,

as even Galvani and his followers had recognized that, after the contractions had become feeble or had entirely ceased, it was only necessary to moisten the muscle and nerve with blood, saliva, or some alkaline or acid fluid to again excite contractions. Thus again did Volta's marvelous dexterity convert Galvani's victory into an apparent defeat.

From this brief sketch of the long controversy between these two distinguished investigators, it is clear that the assertions of both are correct in many respects, and their denials equally incorrect. In all these experiments Galvani maintained the presence of electricity in animal tissues, but denied its development by the contact of metals; Volta maintained that the electricity was only of metallic origin, and denied its existence in the animal tissues.

In the next few years Galvani tried repeatedly, but unsuccessfully, to refute his great antagonist; even Alexander von Humboldt's remarkable experiments, in which all the extraneous influences objected to by Volta were carefully avoided, were of no avail. Humboldt recognized and stated the true position in the following words: "It is indisputably true, and first demonstrated by the observations of the great Ticinian philosopher, that when animals are not convulsed by homogeneous metals they will be so affected when the metals are made heterogeneous by the slightest change in their composition, polish, hardness, form, or temperature. This is the result, it appears to me, of Volta's experiments, and not that muscular contractions can only occur when the metals are heterogeneous."

Owing, however, to Volta's growing influence, Galvani's theory began to lose its adherents. Galvani himself died on December 4, 1798; happily for him, as, in the succeeding year, Volta discovered the pile, which enabled him to triumph over his adversary and to cause almost a total destruction of his theory. For the space of twenty-seven years animal electricity was almost lost sight of, although a few distinguished men, like Humboldt, Erman, and Pfaff, defended it, and Johannes Müller admitted its possibility. Voltaism developed from year to year, and by its aid brilliant discoveries were made in chemistry and physics, foreshadowing the great electrical discoveries and appliances of the present day. Nevertheless, it was this highly-developed voltaism which was destined to show the error in Volta's denial of the existence of animal electricity, though he himself did not live to witness the refutation of his erroneous statements.

In 1820, six years before Volta's death, the Danish philosopher, Oersted, discovered electro-magnetism. He found that an electric current, passing above or below a magnetic needle, immediately deflected it from the meridian. This discovery, in the hands of Schweigger and Poggendorff, led to the construction of the sensitive multiplicator, which in 1825 was rendered still more sensitive by the addition by Nobili of Ampère's astatic needles. By thus giving birth to this delicate and refined

apparatus, "metallic electricity," in the words of du Bois-Reymond, "was to atone for the wrong she had done to her more delicate twin sister, animal electricity, in their earlier years."

After the lapse of twenty-eight years, Nobili was the first to again take up the subject of animal electricity in a scientific spirit. The first use he made of his galvanometer was to seek for the electrical currents in muscles and nerves,—in which, however, he was unsuccessful. The method he adopted was as follows : The spinal column and feet of the frog were dipped into two vessels containing a solution of salt and the multiplicator included in the circuit. As soon as it was closed the limbs were convulsed, but the needle remained stationary. With a new and more sensitive multiplicator, Nobili was enabled to obtain a deflection of twenty and even thirty degrees, and always in a direction which indicated the passage of a current, in the frog, from the feet to the head. This current he called "la corrente propria de la rana," which, later, du Bois-Reymond termed the "frog-current." Of this current, Nobili demonstrated that it is not only present at the moment of closure, but that it is constant, and that its power increases with the number of frogs employed. While he thus discovered the existence of the frog-current, he was led into the error of supposing it was independent of physiological processes, and thermo-electric in origin,—an opinion which was also shared by de la Rive and Magendie.

A few years later, Carlo Matteucci began his investigations in the field of electro-physiology. He started with the endeavor to bring all physiological phenomena into some connection with electrical forces, which necessarily vitiated many of his conclusions and experiments. Nevertheless, he was the first to show, in 1838, by a series of experiments, that the electro-motive action upon which the frog-current depends is independent of the contact of nerve and muscle ; that it is not necessary to prepare the frog according to Galvani's method, but that it sufficed to connect any two points of the frog's body—the back and leg, for example—to obtain a marked deflection of the needle. In 1841 he formulated the following law : The interior of a muscle, placed in connection with any part whatever of the same animal, such as nerve, surface of muscle, skin, etc., produces a current which goes, in the animal, from the muscular part to that which is not so.

In the spring of 1841, Emil du Bois-Reymond, at the suggestion of Johannes Müller, repeated and extended Matteucci's experiments contained in his "Essai sur les phénomenes électriques des animaux" (Paris, 1840). This investigator soon discovered the fact that all muscles and nerves are the seats of electrical currents, which differ in intensity and direction, and that the frog-current is but the resultant of individual currents, whose direction from the foot to the head is merely accidental and not essential. The first results of his investigations were embodied in his paper entitled "Vorläufiger Abriss einer Untersuchung über den

sogenanaten Froschstrom und über die electromotorischen Fische," published in Poggendorff's *Annalen der Physik und Chemie*, January, 1842. With the aid of improved galvanometers, and various forms of apparatus devised by himself, du Bois-Reymond was enabled to accurately determine and formulate the laws relating to the electrical phenomena of muscles and nerves. The result of these laborious investigations was published in his great work, "Untersuchungen über thierische Electricität," 1848, from which year it may be said that electro-physiology took rank as a distinct science.

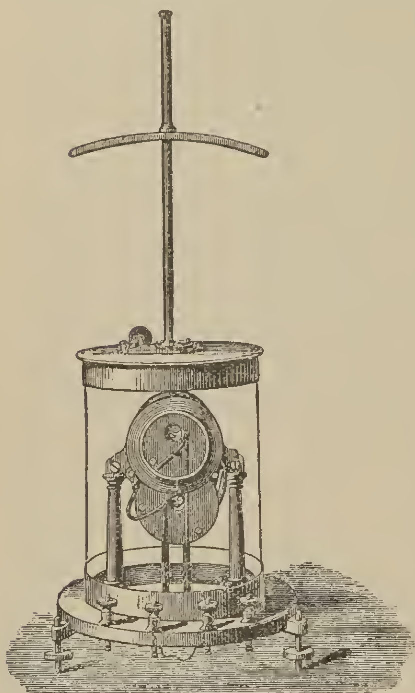

FIG. 1.—THOMPSON'S GALVANOMETER.

METHODS OF INVESTIGATION.

Galvanometer.—In the investigation of the electrical currents of muscles and nerves the physiologist is limited practically to the galvanometer, though in recent years the capillary electrometer has afforded valuable assistance. The essential requisites of any galvanometer used for physiological purposes are that it possesses a high degree of sensitiveness, responding quickly to the influence of extremely-weak currents. These conditions have been realized by the use of small, light needles; the adoption of the astatic system, as suggested by Ampère and Nobili, by which the directive influence of the earth's magnetism is eliminated; and multiplication of the number of turns of the wire by which the needles are surrounded; this latter arrangement, within certain limits, increases the effect of feeble currents with which we have to deal upon the needle. One of the best galvanometers is that of Sir Wm. Thompson (Fig. 1). The principle upon which this instrument is constructed is the same as that of the ordinary galvanometer. Its superiority as an apparatus for refined physiological research lies in the fact that the needles, of which there are two sets, an upper and a lower, are very small and light, not measuring more than an eighth of an inch in length. They are united by a rod of aluminium and arranged astatically. To the upper set of needles there is attached a small, slightly-concave mirror, about six millimetres in diameter. The system of needles and mirrors, so slight and delicate that it hardly weighs more than a grain, is

suspended by a single fibre of silk from the vulcanite frame of the wire coil. Around each set of needles is arranged a coil of fine wire, the upper of which is wound in a direction opposite to that of the lower coil. The terminals of these wires are attached to four binding-screws on the vulcanite disk. The coils are supported by brass uprights, covered by a glass shade, brass bound, which rests upon the vulcanite base, the whole being leveled by three screws. From the centre of the brass disk covering this shade rises a brass rod which carries a movable, curved magnet, slightly magnetized, by which it is possible, by moving it up and down, not only to neutralize the earth's magnetism, but to create an artificial meridian in any direction. For observing the deflections of the needles, a lamp and scale arrangement, such as shown in Figs. 2 and 3, is used, which is placed about three feet from the galvanometer. A small slit in the frame beneath the scale permits a narrow beam of light to pass to the mirror and by it is reflected to the scale. The image is brought to the zero-point by shifting the position of the magnet by fine adjusting-screws. When the

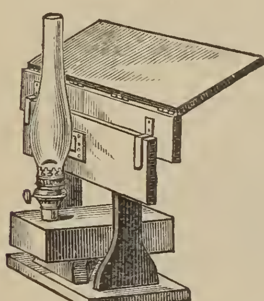

Fig. 2.

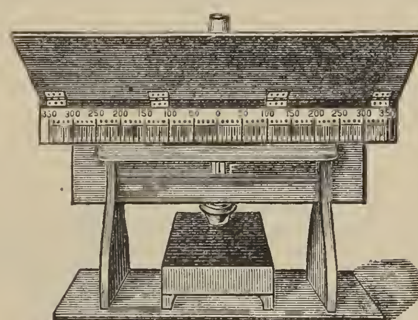

Fig. 3.

electrodes are connected with the two outer of the four binding-screws, and the two inner ones joined together, the current to be investigated will pass through both coils; by removing the connecting wire between the two inner screws, the instrument may be converted into a differential galvanometer, and the relative intensities of two currents easily determined. The particular galvanometer which is used in the physiological laboratory of the Jefferson Medical College has a resistance of 6821 ohms at a temperature of 18° C. A single Daniell element produces through a circuit of 204,660,000 ohms resistance a deflection of 180 degrees on the scale, or a deflection of 1 division through a circuit of 36,838,800,000 ohms resistance. Owing to the extreme delicacy of this instrument it is provided with a shunt, by means of which a fractional part only of the current to be investigated is permitted to pass into the galvanometer. The coils of wire of which the shunt is composed are of varying lengths, and so arranged that they can be united by brass plugs. The resistance of the coils is so graduated, with reference to the resistance of the galva-

nometer, that it is possible to permit $\frac{1}{10}$, $\frac{1}{100}$, or $\frac{1}{1000}$ of the total current to influence the needle.

The tangent galvanometer, or *boussole*, as constructed by Wiedemann, is the form most generally employed in physiological investigations (Fig. 4). It consists primarily of a thick copper cylinder, through which a tunnel has been bored. Within this tunnel is suspended a magnetized ring, just large enough to swing clear of the sides of the chamber. The object of making the magnet ring-shaped is to increase its strength in proportion to its size, and to get rid of the central inactive part. Connected with and passing upward from the magnetized ring through the copper cylinder is an aluminium rod, surmounted by a circular plane mirror. Above the mirror rises a glass tube, which carries on top, on an ebonite support a little windlass, capable of being

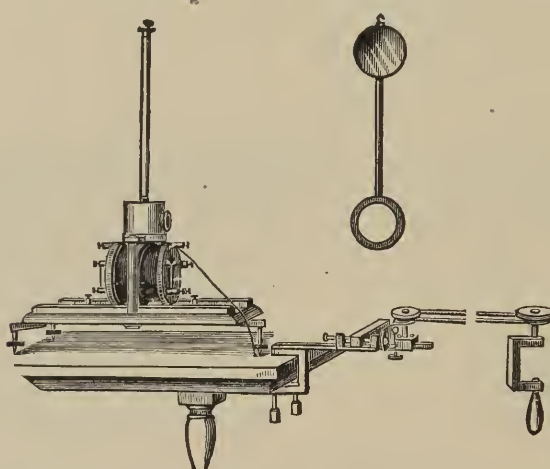

FIG. 4.—WIEDEMANN'S BOUSSOLE.

centred by three small screws. On the windlass is wound a single filament of silk, which passes down the tube and is attached to the mirror. The magnet can, by this contrivance, be raised or lowered and centred in the copper chamber. Deflections of the mirror from currents of air are prevented by inclosing it with a brass cover provided with a glass window. The coils are placed on each side of the copper chamber, and supported by a rod, on which they slide. By this arrangement they can be approximated until they meet and completely conceal the cylinder. By varying the position of the coils the influence of the current upon the needle can be increased or diminished. An advantage which this galvanometer possesses is the damping of the oscillation of the needle, so that it quickly comes to rest after deflection. This is accomplished by the development of induction currents in the copper cylinder, whose direction is opposite to that of the movement of the needle. The in-

strument, therefore, is aperiodic,—that is to say, that when the needle is influenced by a current it moves comparatively slowly until the maximum deflection is reached, when it comes to rest without oscillations. When the circuit is broken, the needle swings slowly back to zero, and again comes to rest without oscillations.

Inasmuch as the needle is not astatic, it is rendered so by the use of an accessory magnet,—the so-called Hany's bar. This magnet, supported by a rod directed perpendicular to the coils, is placed in the magnetic meridian, horizontal to the needle, with its north pole pointing north. By sliding the magnet toward the needle the directive influence of the earth's magnetism is gradually diminished, and when it is reduced to a minimum the needle acquires its highest degree of instability. By means of a pulley an angular movement can be imparted to the end of the accessory magnet in the direction of the magnetic meridian, which serves to keep the needle on the zero of the scale. The deflections of the needle are observed by means of an astronomical telescope, above which is placed a scale divided into centimetres and millimetres, and distant from the galvanometer about six or eight feet. As the numbers on the scale are reversed they will be seen in the mirror in their natural position, and with the deflection of the needle the numbers will appear as if drawn across the mirror. The extent of the deflection is readily determined when the needle comes to rest.

The Capillary Electrometer.—Notwithstanding the extreme sensitiveness of the modern galvanometer, it has been found desirable, in the investigation of many physiological processes, to possess some means which would respond even more promptly to slight variations in electromotive force. This has been realized in the construction by Lippmann of the capillary electrometer. The principle of this apparatus rests upon the fact that the capillary constant or the surface-tension of mercury undergoes a change upon the passage of an electrical current, in consequence of a polarization by hydrogen taking place at its surface. If a capillary glass tube be filled with mercury and its lower end inserted into a solution of sulphuric acid, and the former connected with the positive and the latter with the negative electrode, it will be observed, upon the passage of the current, that a definite movement of the mercury takes place, in the direction of the negative electrode, in consequence of the diminution of its capillary constant or the tension of its surface in contact with the acid. As a reverse movement follows a cessation of the current, a series of oscillations will follow a rapid making and breaking of the current. If the direction of the current is reversed, the capillary constant is increased and the mercury ascends the tube toward the negative pole. From facts such as these Lippmann constructed the capillary electrometer, a convenient modification of which, devised by M. v. Frey, is shown in Fig. 5. This consists of a glass tube, *A*, forty millimetres in length, three millimetres in diameter, the lower end of which is drawn

out to a fine capillary point. The tube is filled with mercury and its capillary point immersed in a 10-per-cent. solution of sulphuric acid. The vessel containing the acid is filled to the extent of several millimetres with mercury also. The mercury in the tube is put in connection with a platinum wire (*a*), and the acid in the vessel with a second wire (*b*). When a constant current passes into the apparatus in the direction from *b* to *a* the mercury is pushed up the tube, and, upon the breaking of the current, it may or may not return to the zero-point. For the purpose of measuring in millimetres of mercury the pressure necessary to compensate this change in the capillary constant produced by the electro-motive force of polarization, the apparatus is provided with a pressure-vessel, *H*, and a manometer, *B*. This electrometer can be applied to any

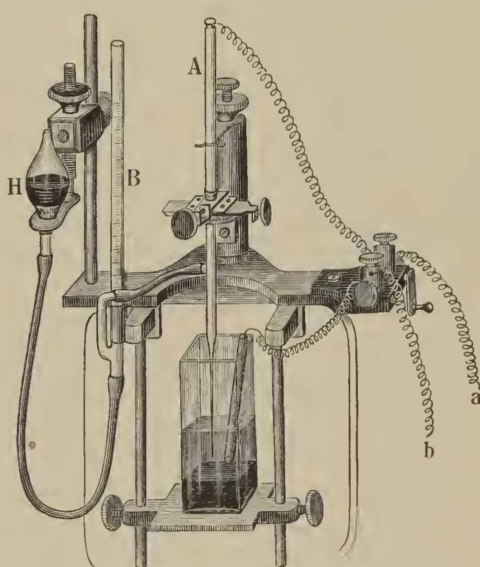

FIG. 5.—CAPILLARY ELECTROMETER.

microscope having a reversible stage. The oscillations of the mercury can then be observed with the microscope provided with an ocular micrometer. The special advantage of the electrometer is, that it will respond instantly to any variation in the electro-motive force, and indicate a difference of potential, according to Lippmann's observation, as slight as the $\frac{1}{10000}$ of a Daniell. These rapid oscillations can be recorded by photographic methods.

Electrodes.—It is essential, in the detection of weak electrical currents with highly-sensitive galvanometers, that the electrodes, which are placed in contact with the tissues, should not only be absolutely homogeneous, as the slightest difference between them will develop a current upon the closure of the circuit, but that they should also be incapable

of producing chemical changes in the tissues which would, in time, lead to a polarization of the electrodes. Should this condition be established, it would give rise to a current in an opposite direction, which would tend to weaken or neutralize the original current, whether artificial or natural. All these difficulties have been overcome by du Bois-Reymond in the construction of what he has termed non-polarizable electrodes, which are also absolutely homogeneous if correctly prepared. Du Bois-Reymond, availing himself of the discoveries of Regnauld, in 1854, that a strip of chemically-pure zinc immersed in a saturated solution of neutral sulphate of zinc, and of Matteucci, in 1856, that ordinary zinc amalgamated and immersed in the same solution, exhibited no polarization, constructed two forms of electrodes, known as diverting vessels and diverting tubes, which are of very general applicability.

The diverting vessel (Fig. 6) consists of a zinc trough insulated by a base of vulcanite, provided with a handle and a binding-screw for the attachment of wires. The inner surface of the vessel is carefully amalgamated, and the outer surface covered with a layer of black varnish. The cavity of the vessel is filled up with the deriving cushions, composed of a series of layers of Swedish filtering-paper, which are bent over the edge of the vessel. These layers are stitched together, and a clean, perpendicular edge obtained with a razor. Before using, they should be saturated with the zinc solution, and when placed in the vessel they are held in position by a strip of ebonite and a rubber band. The trough is then filled with the zinc solution. To prevent the corrosive action of the zinc solution upon the tissues to be examined, a thin clay guard is placed upon the deriving cushion. This guard consists of china-clay worked up into a soft mass with a ½-per-cent. solution of sodium chloride. The guard not only prevents corrosion, but, from the presence of the salt, the secondary resistance which would arise between the liquid conductor and the tissues, and thus diminish the current-strength, is avoided. The diverting cylinder (Fig. 7) consists of a flattened glass tube attached to a universal joint and supported by an insulated brass stand. The lower end of the tube is closed by moistened china-clay, which can be molded into any desired shape. The interior of the tube is filled with

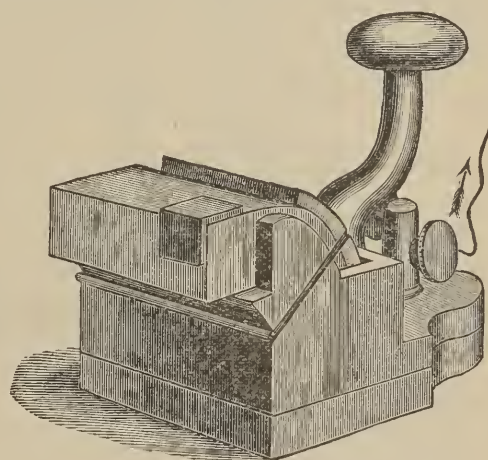

FIG. 6.—DIVERTING VESSEL.

the zinc solution, in which is immersed a slip of amalgamated zinc, the upper portion of which is lacquered. Electrodes of this form are not only serviceable for leading off currents from particular points of muscle and nerve, but are equally well adapted for purposes of electrical stimulation.

The Electrical Properties of Injured Muscles.

Individual muscle-fibres, owing to their small size, are not well adapted for experimental investigation, and present many obstacles to a study of their electro-motive properties. Research is, therefore, limited to groups of fibres as they are found in any given muscle. A complex organ, like a muscle, whose fibres are arranged in a parallel manner, furnishes results which are sufficiently accurate for the formation of definite conclusions. As the primitive bundles of fibres into which a muscle may be divided also exhibit corresponding properties, it is highly probable that individual fibres are similarly endowed, and that the electromotive properties of a muscle are the resultant of those of its component fibres.

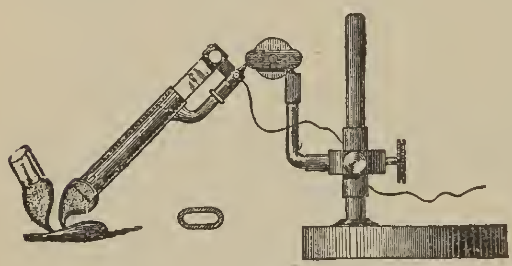

Fig. 7.—Diverting Cylinder.

The demonstration of the fundamental facts of the electrical properties of muscle is most conveniently made with single muscles, and, moreover, with those the arrangement of whose fibres is parallel, *e.g.*, the sartorius, the gracilis, or semimembranosus of the frog. Inasmuch as du Bois-Reymond discovered that the body-current is only the resultant of the currents of individual muscles, experimentation with the entire body, or even with a single limb, is wholly unnecessary.

Muscle-Prism.—If the tendinous ends of one of the above-mentioned cylindrical or oval muscles be removed by a section made at right angles to the longitudinal direction of its fibres, a muscle-prism is obtained, which presents a natural longitudinal surface and two artificial transverse surfaces. A line drawn upon the surface of such a muscle-prism, at a point lying midway between the two transverse sections, constitutes the equator. When the natural longitudinal and artificial transverse sections of a muscle-prism are brought into connection with the wires of a galvanometer whose terminals are provided with non-polarizable electrodes, an electrical current at once develops, the intensity and direction of which are indicated by the deflections of the galvanometer-needle. In all instances it is shown that the current passes from the longitudinal surface through the galvanometer to the transverse sec-

tion, and then through the muscle to the original point of departure; in other words, the former surface is electrically positive to the latter, which is electrically negative. The two points exhibiting the greatest difference of potential, and, consequently, giving rise to the most powerful current, lie in the equator and in the centre of the transverse section. Currents of gradually-diminishing intensity are obtained when the electrode placed on the longitudinal surface is removed from the equator toward either extremity. Feeble currents are developed when two points, situated at unequal distances, either on corresponding or opposite sides of the equator, are connected; in either case, the current flows from the point lying nearest the equator to the point farthest from it. Similar currents are obtained when two points on the cross-section, situated at unequal distances from the central axis, are united, in which case the direction of the current will be from the point lying nearest the periphery toward the central axis, or from the less negative to the more negative point. On the contrary, no current is generated when two points on the longitudinal surface equally distant from the equator, or two points on the transverse surface equally distant from the central axis, are united; such points are said to be iso-electrical. These conditions are shown in Fig. 8.

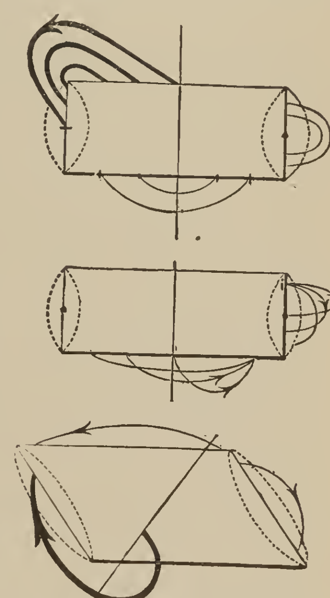

FIG. 8.—DIAGRAM TO ILLUSTRATE THE CURRENTS IN MUSCLE.

The arrow-heads indicate the direction and the thickness of the lines the strength of the currents.

From these facts it is evident that the muscle-prism may be looked upon as presenting, on its longitudinal surface, a series of tension-curves, which surround the prism in a concentric manner, and in a direction at right angles to that of its fibres. At the equator the greatest positive tension prevails, and from this point it gradually diminishes until zero is reached, at the junction of the longitudinal and transverse surfaces. In the same way the transverse section presents a series of tension-curves, all of which are negative with reference to the longitudinal surface; but, in passing from the periphery toward the centre, if the muscle be circular, the negativity gradually increases until it reaches its maximum, at the centre.

The Muscle-Rhomb.—The regularity in the position of points of unequal tension, and the simplicity of the currents when such points are connected by an arch, hold true only for regularly-constructed muscles, as represented by the muscle-prism. Deviations from this assumed normal

condition, both in the position of the points of positive and negative tensions, with reference to the longitudinal and transverse sections, and in the direction of the currents, become apparent when muscles whose fibres are irregularly arranged are subjected to galvanometric investigations. It is oftentimes very difficult to locate definitely in such muscles the positions of the points of opposite and similar potential. As an illustration of the shifting of the cardinal points, it is only necessary to examine a regular muscle-rhomb, constructed by dividing the two extremities of a regularly-constructed muscle in such a manner that the transverse sections are parallel and directed obliquely to the long axis of the fibres. In such a rhomb the fundamental law—that the longitudinal surface is everywhere positive toward the transverse surface, which is everywhere negative—holds true; but the position of the greatest positive electrical potential is no longer on the equator, but situated near the obtuse angle, from which the tension gradually declines as the acute angle is approached. The reverse of this holds true for the position of the points of greatest negative potential upon the transverse surface. Instead of being situated at the centre of the surface, it is now found near the acute angle, from which the tension declines as the obtuse angle is approached. There is, in consequence, a marked displacement in the position of the resulting currents. The equator, in such a rhomb, would be directed obliquely across the muscle, between the two obtuse angles, dividing it into two equal halves. The currents derived from obliquely-directed surfaces du Bois-Reymond has termed "inclination currents," the strength of which increases with the angle of inclination of the transverse surface. Inclination currents are observed in the gastrocnemius muscle, in which the natural transverse surface passes into the tendon in an oblique direction.

The Natural Muscle.—Electrical currents similar to those exhibited by the muscle-prism may be obtained from the natural muscle, which yet retains its tendinous or aponeurotic extremity. The natural ends of the muscular fibre inclosed by sarcolemma and tendon are spoken of as the natural transverse section. In his earlier experiments, du Bois-Reymond recognized no difference in the electrical properties of the natural and artificial cross-sections; but, subsequently, he observed that if certain precautions were taken not to injure the tendon, either chemically or physically, the negativity of the natural cross-section was inconstant. If examined immediately after removal from the body of the animal, after observing the above precautions, the electrical opposition between the longitudinal and natural cross-sections may be entirely absent, or, as is frequently the case, the latter surface may be positive in character. This is particularly true of animals which have been subjected to a temperature of 0° C. The negativity is at once developed if the tendinous expansion is chemically changed, as was the case by the saturated salt solution in the electrodes employed by du Bois-Reymond in his earlier

experiments. The layer of muscle-substance in the immediate neighborhood of the tendon which is so often neutral or even positive in its electrical relations he has termed the parelectronomic (from *para nomos*, contrary to law). All muscles possess this paralectronomic layer, and it is only necessary to remove it to make a caustic artificial cross-section, to permit the negativity of the living muscle to manifest itself.

The muscle-currents such as those above described have been shown to be present in the muscles of various representatives of mammals, birds, and reptiles, in the muscles of crustacea, and in the earthworms. The tibialis anticus, from the amputated leg of man, examined hardly a quarter of an hour after the operation, exhibited such a marked electrical difference between the longitudinal and transverse that the needle was thrown violently against the guards. (Du Bois-Reymond, "Untersuchungen über thierische Electricität," Bd. i, S. 524.) Du Bois-Reymond, to whom we are indebted for a knowledge of all the preceding facts, considers the currents to be intimately connected with the living condition of the muscle, and essential to the performance of its functions.

The Electro-motive Force of the Muscle-Current.—The muscle-current developed by connecting the longitudinal and transverse surfaces possesses an electro-motive force the amount of which can be estimated by the method of compensation devised by Poggendorff and modified by du Bois-Reymond. The idea involved in this method is to send first through the galvanometer the maximum strength of the muscle-current, and then, by means of the rheocord, to send a fractional part of the Daniell current in an opposite direction, just sufficient to neutralize the effect of the muscle-current upon the needle. When the two currents are equal and opposite in amount, the needle remains stationary at the zero-point. The fraction of the Daniell thus becomes a measure of the muscle-current, and if the rheocord wire has been previously graduated in millimetres, each of which represents a fraction of the electro-motive force of the Daniell current, it becomes a simple matter to determine the electro-motive force of the muscle in terms of the Daniell from the position of the slides on the rheocord wire. The electro-motive force of the frog-current was found by du Bois-Reymond (*Archiv für Anat. und Phys.*, 1867) to vary from 0.037 to 0.075 D.

Conditions Influencing the Development of the Muscle-Current.—As the existence of the muscle-currents is connected with those chemical changes underlying all nutritive processes, they do not disappear at once upon the death of the animal, but continue for a variable length of time, though with gradually-diminishing power. All those influences, therefore, which hasten or retard destructive chemical changes will influence the time of disappearance of the currents. Though the current diminishes in strength from the first observation, there is not infrequently observed for a short period an increase in the electro-motive force, which

has been attributed to an additional current passing from the cross-section to the longitudinal surface, developed by the contact of the fluids of the electrodes with the muscle-tissues. With the separation of the muscle from its blood-supply, it begins to experience a series of retrogressive changes which finally eventuate in rigor mortis. As this condition is approached the muscle exhibits simultaneously a diminution of its currents and a loss of its physiological properties. The dependence of the muscle-current for its existence upon the normal metabolism of the tissue is shown by the fact that, after the disappearance of the current and the beginning of rigor mortis, it will re-appear if the latter condition be removed by the introduction of a stream of fresh defibrinated blood

Among the influences which affect in a significant manner the muscle-current must be mentioned temperature. It was originally shown by du Bois-Reymond that if a muscle be placed in distilled water at a temperature of 50° C. it contracts to a shapeless mass, loses its irritability, and becomes devoid of electrical properties. This is to be explained by the coagulation of the albuminous constituents, upon the normal composition of which the physiological and electrical properties of the muscle depend. A similar destructive influence upon the muscle-current has that degree of cold which impairs the vitality of the muscle. After thawing of the muscle no current is obtainable. Within the limits of 35° C. and 40° C., as is well known, all vital processes proceed most actively; the electro-motive force will, therefore, be increased with slight elevation, and decreased with a lowering of the temperature. According to Hermann, the variations between the above-mentioned limits will amount to as much as 22 per cent. The same observer (*Archiv für die gesammte Physiologie*, Band iv, 1871) has also shown that heating different points of the longitudinal surface renders them strongly positive toward the cooler portions, though this does not hold true for the transverse surface. Between warmer and colder portions of muscle-substance a difference of potential always exists, the condition of the parts lying between being unimportant.

The dimensions of the muscle-cylinder have also a slight influence upon the current-strength. By employing the method of compensation du Bois-Reymond has made the observation that within certain though not well-defined limits the electro-motive force increases with both the length and thickness of the muscle. By the intercalation of two corresponding pieces of muscle of unequal length in the galvanometer circuit, and by placing the electrodes in such a position that the currents conducted off pass into the galvanometer in an opposite direction, it was observed that the current from the larger muscle exerted a more powerful influence upon the needle than the current from the shorter muscle. In the same way it was shown that if two muscles the same length but of unequal thickness are opposed to each other, the thicker muscle always yields a stronger current than the thinner one.

Influence of the Contraction on the Muscle-Current.

Negative Variation.—The first accurate observations of the influence of the contraction upon the muscle-current were made by du Bois-Reymond. It was shown by this observer that as soon as the muscle enters the state of activity there is a diminution in the electro-motive force between the longitudinal and transverse surfaces, with a resulting diminution in the intensity of the muscle-current. This change in current-strength has been termed *negative variation*. In order to observe this negative variation of the muscle-current, it is only necessary to insert between the terminals of the galvanometer circuit the longitudinal and transverse surfaces of the gastrocnemius muscle. The powerful current thus obtained causes a marked deflection of the needle, which, after a few oscillations, comes to rest. If now the nerve in connection with the muscle be tetanized with the interrupted or induced current, the muscle passes into the condition of tetanus; at once the needle is observed to return toward the zero-point and remain in this neighborhood as long as the tetanic contraction continues. With the cessation of the stimulation the needle is again deflected outward by the re-establishment of the muscle-current, without, however, attaining its former position. There thus appears to be a decrease in the strength of the muscle-current during muscular contraction, the extent of which is proportional to the intensity and duration of the contraction. From the inertia of the galvanometer needle and the short duration and force of the negative variation du Bois-Reymond was unable to show this change in a single muscle pulsation. It was for this reason that tetanic stimulation was employed.

There can be no doubt that this diminution in the strength of the current is intimately connected with muscle activity, and not the result of an escape of the electrical current from the electrodes, inasmuch as the same variation follows chemical, thermal, or mechanical stimulation. Nor can it be due to any change in the position of the electrodes, for if the muscle be clamped so as to prevent displacement during the contraction the activities arising within the muscle will, nevertheless, produce a diminution of the current.

The question as to whether this negative variation during tetanus is the result of a steady, continuous decrease of the electro-motive force, or of a series of rapid and successive variations in the intensity of the muscle-current, cannot readily be shown by the galvanometer from the inertia of the needle. The physiological rheoscope, however, affords a ready means of elucidating this question. It was discovered by Matteucci that, if the nerve attached to the gastrocnemius muscle be laid upon the thigh of another animal in such a manner that the nerve forms an arch uniting negative and positive surfaces, with every contraction of the latter the gastrocnemius is thrown into pulsation. The explanation of this secondary contraction was furnished by du Bois-Reymond. The

current from the primary muscle undergoing a negativity produces a negative variation of the portion of the current which passed into the applied arch of nerve; and, as every change in the intensity of a current excites a nerve-impulse, a secondary contraction follows. Moreover, if the primary nerve be repeatedly stimulated, the thigh passes into the tetanic state, and simultaneously the neighboring muscle—the gastrocnemius—passes into the condition of secondary tetanus. As only the second muscle can be tetanized by a series of discontinuous impulses descending the nerve,—the result of rapid variations in the strength of its current,—it is evident that the primary muscle is experiencing similar variation in its electrical conditions. Confirmatory proofs of alternating variations in the strength of the muscle-current during the tetanic state are furnished by the oscillations of the mercury in the capillary electrometer and by the sonorous vibrations of the telephone when these instruments are employed instead of the physiological rheoscope.

While the above means of investigation reveal an intermittent variation in the intensity of the muscle-current, no evidence is adduced which would indicate whether it undergoes merely a partial diminution, or whether it is entirely obliterated, or whether it experiences a reversal, passing beyond the zero-point to a greater or less extent in a positive direction.

The answer to this, as well as other questions relating to the characteristics of the negative variation, was first given by J. Bernstein ("Untersuchungen über den Erregungsvorgang im Nerven und Muskelsysteme," 1871), who, by means of the differential rheotome, was enabled to study it in all its phases. The principle of this instrument consists in the rotation of a wheel at a given rate, which closes a circuit stimulating a nerve or an end of a muscle, as well as a circuit diverting the muscle-current through the galvanometer; by arranging the apparatus so that the stimulating current is closed at varying intervals before and after the diverting current, it becomes possible to determine the rate of propagation, form, extent, and time durations of this negative change. By these investigations it was shown that, after stimulation of one extremity of a muscle by an induction-shock, a definite and measurable interval of time elapses before the molecular changes thus initiated reach the electrode upon the longitudinal surface of the muscle, and which reveal themselves through the deflection of the galvanometer-needle in a direction indicating a negativity of the original muscle-current. This interval of time increases or decreases with the distance of the stimulating electrodes from diverting electrodes. Inasmuch as the time occupied by the molecular disturbance in arriving at the electrode and the length of muscle are proportional to each other, it is easy to determine the rate of propagation by dividing the latter by the former. This Bernstein calculated to be about three metres per second. It was also shown that this modification of the muscle, after its first appearance, rapidly reaches a

maximum and then more slowly declines; in other words, it propagates itself in the form of a wave. The length of time required for an entire wave to pass any given point of the muscle was estimated at 0.0033 second, from which value and from that of the rate of propagation it is easy to see that the wave-length approximates ten millimetres. With reference to the extent of negativity which the muscle-current undergoes during the contraction, Bernstein (*op. cit.*, p. 68) observed that, at the highest point of the negative wave, the muscle-current was entirely obliterated, though there was no evidence of a reversal in the opposite direction. Moreover, a further observation of interest was the apparent fact that the negative variation passes over the muscle entirely during the latent period [1] and actually precedes the movement of the contraction wave.

Burdon-Sanderson ("Proceedings of the Royal Society," May 1, 1890; *Centralblatt für Physiologie*, 1890, Band iv, S. 185), however, has brought forward incontrovertible evidence that the two processes,—the negative variation and the contraction wave,—instead of being separated in time, occur simultaneously. In these careful experiments the moment of stimulation, the electrical response as revealed by the capillary electrometer, and the change of form were recorded at the same instant by photographic methods. An analysis of the results shows that the electrical wave, instead of preceding the contraction wave, actually accompanies it. The latent period also, the time elapsing between the stimulation and the simultaneous appearance of the two processes, was shown to be very much shorter than that given by Yeo, and amounting to not more than the 0.0035 second. Sanderson concludes, from his experiments, that "all those theories, therefore, of the excitatory process in muscle which rest on the supposed fact that electrical disturbance is a concomitant of the period of latent stimulation, fall to the ground."

Electrotonus—The passage of a constant galvanic current through a limited portion of a muscle produces a change in its electrical condition to which the term electrotonus has been given. It has long been supposed that the electrotonic condition was limited to that portion of the muscle included between the two electrodes. The change of condition produced by the constant current relates to the natural muscle-current, and depends upon an inner polarization of the muscle. The constant current develops within the muscle an opposing current which may strengthen or diminish the pre-existing current according to the direction. If the constant current has the same direction as the muscle-current, the opposing current will, by adding itself to the latter, strengthen it; if,

[1] It was shown by Helmholtz (Archiv für Anat. und Phys., 1850, S. 276), in his classical researches upon the time relations of the different phases of a single muscular contraction, that a short but measurable interval of time elapsed between the application of a momentary stimulus and the beginning of the contraction, which he termed the "latent period," the duration of which he stated to be 0.01 second. Tigerstedt and Yeo have, by improved methods, reduced it to the 0.005 second.

however, the constant current is opposite in direction to the muscle-current, the opposing current will diminish the strength of the muscle-current. The electrotonic condition endures for some time, though with gradually-diminishing intensity, after the withdrawal of the constant current. Hermann ("Handbuch der Physiologie," Band ii, S. 168) states that he has been able to demonstrate the existence of the electrotonic condition also in the extra-polar region. Currents flowing in the same direction as the polarizing were obtained from the portion of the muscle in connection with the galvanometer, the strength of which increased with the latter. These currents are better developed on the side of the anode than on the side of the cathode.

Electrical Properties of Uninjured Muscle.

Currents of Rest.—The laws formulated by du Bois-Reymond as to the existence of electrical currents in uninjured as well as injured muscle, and the negative variation which they undergo during contraction, have been opposed by Professor Hermann, who, from a long series of accurate experiments, denies the existence of currents in passive and absolutely uninjured muscle, and attributes the currents which are obtained to injuries of the surface of the muscle-substance due to the methods of preparation. However carefully a muscle may be removed from the body, various points on its surface become altered chemically or physically, whereby differences of potential are established, the injured part becoming negative to the uninjured. The currents which are observed during muscular activity Hermann regards as the result of the action of electromotive forces which come into operation at the seat of excitation, and not as the result of a negative variation of pre-existent currents. To such currents the term "action currents" has been applied.

The negativity of the natural cross-section which led du Bois-Reymond to regard these currents as pre-existing in all living muscles was shown by himself to be due to the corrosive action of the salt solutions of the electrodes upon the muscle, thus causing an artificial cross-section. When this source of error was eliminated, it was noticed that the natural muscle-end exhibited electrical actions which were quite irregular in relation to the longitudinal surface, being sometimes neutral, at other times negative or even positive. This difference in the behavior of the natural and artificial cross-sections du Bois-Reymond attributed to a peculiar property of the natural end of the fibres, termed by him parelectronomia. The experiments which were subsequently made by du Bois-Reymond to obtain currents from muscles without removal of the skin were vitiated by the existence of powerful skin-currents, which were directed from without inward. These currents he was enabled to set aside, however, by destroying, at different points, the integrity of the skin by cauterization with a saturated solution of salt, after which the muscle-currents could be obtained. It was concluded, from these ex-

periments, that in animals not deprived of skin natural muscle-currents are pre-existing.

Professor Hermann did not regard this experiment as conclusive evidence for the pre-existence of the currents, and raised the objection that by the time the skin-currents were set aside by the caustic the underlying muscle-substance was also more or less injured, as, indeed, was shown to be the case when nitrate of silver was employed as the caustic agent. This he regarded as a sufficient explanation for the appearance of the current, especially as it increased in strength with the extent of cauterization. In subsequent investigations (*Archiv für die Gesammte Physiologie*, Band iii, 1870) Hermann demonstrated that, by immersing a curarized frog in a solution of corrosive sublimate for ten seconds, the skin-currents could be entirely abolished without producing any discoverable lesion of the muscular surface. After washing and drying the animal, it was only possible to obtain irregular currents of indefinite direction, and to which no physiological significance could be attached. He also succeeded in demonstrating that the gastrocnemius muscle might be so prepared by the avoidance of all pressure, change of temperature, and, above all, the contact of the irritating secretion of the skin; that it would exhibit the same want of constancy and regularity in the distribution of electrical inequalities. In fish, where from the absence of skin-glands there are no skin-currents, and where neither cauterization nor mechanical preparation is necessary, it was impossible to obtain currents from the muscles if the animal was curarized and kept at room temperatures (*Archiv für die Gesammte Physiologie*, Band iv, 1871). One of the most favorable muscles for isolation without injury is the heart, and Englemann showed, in 1874, that when examined in a state of rest no currents whatever could be detected. The same observer has also found (*Archiv für die Gesammte Physiologie*, Band xv, S. 328) that an ordinary muscle which has been divided subcutaneously, and therefore presents an artificial cross-section which is negative to the longitudinal surface, will soon again become streamless under the influence of the circulation and innervation.

From experiments such as these Hermann concludes that, in absolutely uninjured passive muscle, no current is demonstrable, and that the so-called muscle-current is intimately connected with injuries of its surface, and more especially with the artificial cross-section. All the electrical phenomena of a resting muscle depend upon the difference of potential between the living longitudinal surface and the dying transverse surface, which becomes electrically negative to the former.

Action Currents.—The currents which are obtained from a muscle during contraction Hermann regards as the result of electro-motive forces which develop during the propagation of the excitation wave, and not related in any way with a negativity of any pre-existent current. As these currents are connected entirely with the active state, he has termed

them "action currents," which, moreover, may be either phasic or tetanic as they relate to a single or a series of successive contractions. The term "phasic" is applied to the two currents which are observed when a wave of excitation passes along the muscular fibre. The first flows in the muscle, in the direction of progress of the excitation wave,—first phase; the second in the reverse direction,—second phase. These currents are due to the fact that each led-off point becomes negative with reference to the other as the excitation wave passes beneath it. The term tetanic, or decremential, is applied to the single current which is observed in a tetanized muscle, the direction of which in the muscle coincides with that of the excitation wave. In the tetanic state, in which the excitation waves follow each other in rapid succession, there should be no difference of potential, the negative tracts following each other so closely that all portions of the muscle remain in the same electrical condition. This would be the case if it were not that the wave of negativity diminishes as it travels. Hence, if any point of a tetanized muscle near the seat of excitation be compared, by means of the galvanometer, with any point situated at a greater distance from it, the former will be found negative to it. The views entertained by Hermann as to the origin and character of the action currents are based upon observations and experiments made by himself and other physiologists.

Du Bois-Reymond, in 1859, observed that when he tetanized an apparently uninjured gastrocnemius muscle, which, owing to the presence of the parelectronomic layer, exhibited no current, a descending current in the muscle always manifested itself. This descending current, or the first phase of the action current, according to Hermann, was comparable in its direction to the negative variation of the resting muscle-current. The passage of this descending current in uninjured muscle, during a single contraction, will develop a secondary contraction, and during tetanus will develop secondary tetanus; from these facts it must be inferred that to each single contraction and to the successive contractions in tetanus there corresponds a momentary descending current. This current is less marked, its development slower, and its after-effect more considerable than the negative variation of the current from an artificial cross-section.

According to the observations of du Bois-Reymond, also, when two symmetrical points on the longitudinal surface are united, no current is obtainable from the muscle, either in the resting or active condition, when stimulated through the nerve. Bernstein showed (*Monatsberichte der Berliner Acad.*, 1867, p. 444), however, when two such points are connected and the stimulation applied directly to the one end of the fibre, that with the progress of the excitation wave each led-off point became negative toward the other as the wave passed over it; in consequence, the needle indicated first a "negative," then a "positive," variation, or a diphasic action current.

The first accurate experiments undertaken with a view of analyzing the negative variation current (action current of Hermann) of an uninjured muscle during a single contraction were made by S. Mayer with Bernstein's rheotome (*Archiv für Anatomie und Physiologie*, 1868, S. 655). He employed for this purpose the gastrocnemius muscle of a non-curarized frog, connecting both tendinous ends with the galvanometer and exciting contraction by single induction shocks directed through the sciatic nerve. The excitation wave proceeded, in this instance, not from the end of the muscle-fibre, but from the end-plate of the nerve. It was observed in these experiments, from the movement of the needle, that the negative variation consists of two phases, in the first of which the lower end of the muscle becomes positive, and in the second the upper end, indicating, according to Hermann, the passage of, first, a descending, and, secondly, of an ascending action current. Holmgren, who had previously observed the same phenomena in the gastrocnemius, believed that the first phase of the negative variation took place entirely in the latent period, and the second in the stage of beginning contraction.

Hermann (*Archiv für die gesammte Physiologie*, 1877) repeated these experiments with a special apparatus,—the Fall rheotome,—by means of which the galvanometer circuit was closed by a falling body, for a brief moment, at a definite period of time after stimulation. In this way he found, contrary to former observations, that the transition of the descending into the ascending current did not coincide with the beginning of the contraction, but took place entirely in the latent period, as both phases appeared even when the rheotome was so arranged that the circuit was closed only up to the moment of contraction. Du Bois-Reymond attributed this double variation to an interference of the effects at the two ends of the muscle, for when he united the middle and tendinous end of a regularly-constructed muscle he observed only the ordinary negative variation or a single action current passing in the direction of the tendon. If both ends are led off, the currents passing in opposite directions from the point of excitation (the end-plate of the nerve), being of equal strength and requiring the same period of time for their propagation, would neutralize each other, and no deflection of the needle would result. Du Bois-Reymond supposes the negative variation here to be due to excitatory changes at the tendinous ends, which appear more suddenly and are accomplished in a shorter time at the lower end than at the upper, in consequence of which the effect from below upward has the advantage, as regards time. Hermann rejects this explanation, and asserts that when the middle and tendinous end of a regularly-constructed muscle are connected with the galvanometer and a single contraction excited through the nerve the deflections of the needle indicate a current of a diphasic character,—the first phase being atterminal, indicating a current directed toward the end of the

muscle; the second phase being abterminal, indicating a current in the reverse direction. The second phase was always found to be the weaker, and was always wanting when the end of the muscle had an artificial transverse section.

The explanation of this diphasic variation Hermann finds in the wave-like propagation of the excitation tract. As this tract appears first at the point of entrance of the nerve, and travels thence to both ends of the muscle, there must arise, as a result of the progressing negativity, first, the atterminal action current, indicating that the end of the muscle has become positive to the middle; secondly, the abterminal, indicating the reverse condition. The feebleness of the latter current, as compared with the former, arises from the decrease of the excitation wave during its propagation; and as the decrement increases with a diminution in the functional activity of the muscle, either by fatigue or gradual death, the abterminal phase gradually disappears. As the artificial cross-section cannot develop an electro-motive force, the abterminal is entirely absent.

With regard to the location of the electro-motive force giving rise to the action current, du Bois-Reymond assigns it to the parelectronomic end of the muscle. If, however, this force has its origin in the decrement, as Hermann terms it, then it ought to be distributed almost equally over the entire length of the fibre. This supposition Hermann proved true when he showed that the strength of the action current is proportional to difference in the distances of the conducting electrodes from the nervous equator, meaning by this term that cross-section of a muscle which represents the mean position of the point of entrance of the nerve.

Currents in a Living Man.—The existence of electrical currents in the uninjured muscles of a living man, though assumed by du Bois-Reymond, was rendered difficult of proof by the resistance offered by the skin, by inequalities of temperature, by glandular secretions, etc. Nevertheless, he was able to demonstrate apparently that the voluntary contraction of the muscles of an arm or leg was attended by an electrical change similar to that observed in a muscle after removal from the body, and which he regarded as a negative variation of an hypothetical resting current. The experiment made to show this was as follows: The index fingers were dipped into diverting vessels containing a salt solution, each of which was connected with the galvanometer. As the arrangement of muscles on both sides of the body is symmetrical, the currents conducted off from both fingers were equal in strength and the needle remained quite stationary. When the muscles of one arm were contracted voluntarily, a deflection of the needle took place, which indicated that the contracting arm became negative, and that a current was passing from the passive arm through the galvanometer. When the opposite arm was contracted, the deflection occurred in the reverse direction. The objections to the conclusions drawn from this experiment are numerous. Hermann denies that the current observed is the result of

changes in the muscle, but is a skin-current directed from without inward. In curarized cats it was shown that, when both feet were connected with the galvanometer, stimulation of the sciatic nerve was followed by a simultaneous secretion of perspiration and the development of a powerful current, which passed into the irritated limb. In atropinized cats, on the contrary, stimulation of the nerve was followed neither by sweating nor the development of a current, even though the muscles were contracting vigorously. From this experiment Hermann asserts that a curarized man would show the du Bois-Reymond current, even in the absence of the muscular contraction; while in an atropinized man it would be absent, in spite of the contraction.

Hermann subsequently (*Archiv für die gesammte Physiologie*, 1877, Bd. xvi) demonstrated, however, the presence of action currents during a single contraction of the muscles of the human forearm, similar to those observed by him in the uninjured muscles of the frog. The arrangement of the experiment was, briefly, as follows: The forearm was surrounded by two twine electrodes saturated with zinc solution, one being placed at the physiological middle,—the nervous equator,—the other at the wrist. Both electrodes were then connected with the galvanometer. When the brachial plexus was stimulated in the axillary space, the deflections of the galvanometer needle, when analyzed with the repeating rheotome, indicated phasic currents with each single contraction. In the first phase —atterminal—the wrist became positive, and in the second—abterminal— it became negative. The action currents which are observed in the frog's muscle were thus shown to be present in the living human muscle, with this difference, however: that the second phase,—abterminal,—instead of being weaker in man, is equally strong with the atterminal. This experiment also revealed the fact that the rapidity of propagation of the excitation wave was much greater in man, amounting to about twelve metres per second.

Theories of the Electrical Phenomena of Muscle.

The Molecular Hypothesis.—Starting from the view that the electric currents of muscles have their origin in the peculiar structure of living muscle, du Bois-Reymond assumed, in explanation of such currents, the existence in the muscle of electro-motive molecules imbedded in some indifferent medium. He supposes that the muscle consists of peripolar-electric molecules, positive at the equator and negative at either end, each of which is composed of two smaller dipolar-electric molecules with their positive ends turned toward each other. In addition to this structural arrangement, it is also assumed that every pair of dipolar molecules is inseparably united, so that injury to one is immediately followed by death of the other. It can thus be explained why every artificial surface of the muscle is negative. If the section be made between two adjacent pairs of dipolar molecules, then only negative surfaces present themselves

at the surface, and if the section be made through the positive plane of a dipolar pair, the non-injured twin molecule at once dies, thus enabling the negative surface of an adjoining molecule to present itself. To explain the parelectronomic phenomena, du Bois-Reymond assumes that at the natural end of the fibres there is a layer of bipolar "parelectronomic molecules" which do not turn the negative, but the positive, surface to the tendon.

The negative variation is explained by a decrease of electro-motive force of the molecules, or a new arrangement of them by which their electro-motive effect is weakened. The negative variation of parelectronomic muscles is explained by the hypothesis that the parelectronomic molecules, which compensate to a greater or less extent the current of the resting muscle, do not partake of the negative variation to the same degree as the normal molecules, and, in consequence, their own variation is unable to compensate that of the remaining normal part of the muscle. It is for this reason that a streamless parelectronomic muscle shows the same variation as if it had an artificial cross-section. The negativity of the excitation wave is explained by the further assumption that the portion of the muscle being stimulated represents a relatively indifferent conductor, because its former positivity is now momentarily abolished from the negative variation of its molecular forces. The negative electricity, therefore, which is always present at the negative cross-sections of the resting part, is simply conducted to the stimulated part, which becomes momentarily negative.

The Alteration Hypothesis.—In 1867, Professor Hermann proposed a new theory as to the origin of the electro-motive forces which, so far, has apparently explained all the phenomena. He terms this the alteration theory, because it reduces all electro-motive phenomena of muscle to a two-fold alteration of its substance. In the first place, he starts from the fact that a section of a muscle is followed, in a short time, by death of the contents of its fibre. Assuming that the dying substance reacts negatively toward the living, he is enabled to explain readily and satisfactorily all the phenomena of the resting muscle. As the electro-motive force, according to this view, has its seat at the surface of separation between the dying and living substance, he terms the current the demarkation current. The phenomena observed during activity are further explained by the simple and plausible assumption that not only beginning death, but even stimulation, makes the affected substance negative to the remainder of the muscle. All the forms of action currents can thus be explained without any further auxiliary hypothesis.

Hermann regards the following four propositions sufficient to explain the origin of all the galvanic phenomena of living tissues: 1. Localized death in continuity of protoplasm, whether caused by injury or by metamorphosis (mucous, horny), renders the dead part negatively electrical to the unaltered part. 2. Localized excitation in continuity

of protoplasm renders the excited part negatively electrical to the unaltered part. 3. Localized warming in continuity of protoplasm renders the warm part positive; localized cooling, the cold part negative to the unaltered part. 4. Protoplasm is strongly polarizable on its limiting surfaces (first shown as regards the protoplasm inclosed in tubes of muscles and nerves); the polarization constant decreases on excitation and on dying. ("Translations of Foreign Biological Memoirs," 1887, p. 328, edited by Burdon-Sanderson.)

Electrical Properties of Injured Nerves.

After the discovery of the existence of electrical currents in muscles, numerous attempts were made to determine the existence of similar currents in nerves and to identify, if possible, the nerve-principle with electricity. It was reserved for du Bois-Reymond, however, to first definitely detect the presence of electrical currents in nerves, which he was enabled to do by means of the improved methods of investigation alluded to in the previous section. This observer discovered that the electrical properties of nerves have a striking similarity to those of muscles, and that the laws governing the latter are equally applicable to the former.

Nerve-Cylinder.—The nerve-cylinder, obtained by making two transverse sections of any given nerve at right angles to its long axis, is best adapted for the application of the nerve-current. Such a cylinder presents, as in the case of the muscle, a natural longitudinal surface and two artificial transverse surfaces; a line drawn around the nerve-cylinder, at a point lying midway between the two end-surfaces, constitutes the equator. An artificial longitudinal surface is difficult to obtain, from the small size of the nerve-bundles. The electrical phenomena of the nerve-cylinder, when examined with the galvanometer, are found to obey the same laws as those governing the muscle. Strong currents are obtained when the natural longitudinal and the transverse surfaces are placed in contact with the diverting cushions of the electrodes. The direction of the current, of which the deflection of the needle is an indication, is constantly from the longitudinal surface through the galvanometer to the transverse surface. The strength of the current obtained by uniting these two surfaces will diminish or increase, according as the electrode on the longitudinal surface is removed or brought near to the equator. Weaker currents are obtained when two asymmetrical points on the longitudinal surface are connected, in which case the point lying nearer the equator becomes positive, to that more distant, which is negative. When two symmetrical points on the longitudinal surface, equidistant from the equator, are united, no current is obtainable. From these facts it is evident that all points on the longitudinal surface of the nerve-cylinder are electrically positive to the transverse surface, and that the point of greatest positive tension is situated at the equator, from which it grad-

ually decreases toward the transverse section. As to whether this latter surface exhibits differences of potential between its centre and circumference it is difficult to determine, as the small area of the surface excludes it from accurate investigation, though it is quite probable, from the analogous electro-motive properties of muscle, that similar differences of potential are present. Mendelssohn (*Archiv für Anat. und Physiologie*, 1885) has recently shown that when the two transverse sections of a nerve-cylinder are united, a current—the axial current—is obtained which flows in the nerve in a direction opposite to that of the direction of the nerve-impulse. In motor or efferent nerves it flows from the periphery toward the centre, and in sensory or afferent nerves in the contrary direction. The small size of the nerve-trunks renders an investigation of oblique surfaces for evidences of inclination currents impossible.

The Electro-motive Force.—The electro-motive force of the nerve-current, obtained by uniting the longitudinal and transverse surfaces, varies in strength with the length and thickness of the nerve, a long section of a nerve showing, under similar conditions, a more powerful current than a short section, while a nerve with a large transverse section will exhibit a stronger current than a nerve with a small transverse section. From the experiments of du Bois-Reymond, the electro-motive force of the strongest nerve-current in the frog is equal to the 0.002 of a Daniell, and in the rabbit to 0.026 D.

Conditions Influencing the Development and Duration of the Nerve-Current.—The current present in any given nerve-fibre does not disappear at once upon the death of the body, but disappears gradually until, sooner or later, it entirely ceases to manifest itself. After the transverse section of a nerve-cylinder has ceased to exhibit negativity in relation to the longitudinal surface, independent of either mechanical or chemical injuries, the production of a new section will be followed by a return of the current in its original intensity. Inasmuch as the development of the current is intimately related to the living condition of the nerve, all those influences which hasten the molecular disintegration will cause a disappearance of the current. Excessive heat or cold, mechanical injuries, acids, alkalies, repeated induction shocks, all tend, through the production of changes in the contents of the nerve-fibre, to diminish the current. The duration of the current varies considerably in different parts of the nervous system and in different classes of animals, there being no physiological change comparable to that producing rigor mortis in muscles, which determines definitely the cessation of the current. Indeed, there does not appear to be any absolute connection between the existence of excitability and the development of the current, as the observations of Schiff ("Lehrbuch der Muskel und Nervenphysiologie," 1858, S. 69) have shown that after separation from the central nervous system the nerves will exhibit a current for from eight to fourteen days

after they have lost their excitability through degenerative changes. The electro-motive forces disappear first in the nerve-fibres of the brain, then of the spinal cord, and lastly in the nerves themselves, and in a direction from their origin toward their termination. In warm-blooded animals, both mammals and birds, the electro-motive properties disappear more rapidly than in cold-blooded animals, most probably in consequence of the more rapid decline of all those chemical changes underlying the general nutritive process. Not unfrequently in warm-blooded animals, less frequently in frogs, a reversal of the current is observed, more especially if the nerve be rapidly dried or subjected to heat, although the same phenomenon is observed under normal conditions. In the latter case, it has been attributed to an accumulation of electrolytic products at the limiting surface, which have given origin to a polarization current flowing in a direction opposite to that of the natural current.

The Influence of Stimulation upon the Nerve-Current.

Negative Variation.—It was shown by du Bois-Reymond, shortly after the discovery of the nerve-current, that the activity of the nerve, as well as the activity of the muscle, is accompanied by a change in its electro-motive condition or a diminution of potential between the longitudinal and transverse surfaces, and in consequence a negative variation of the natural pre-existing current. This change in the electro-motive forces can be readily demonstrated by means of the galvanometer during tetanic stimulation, or by the capillary electrometer during a momentary stimulation by a single induction shock. When the transverse and longitudinal surfaces are connected with the terminals of the galvanometer wires, and the current permitted to deflect the needle, stimulation of the nerve is at once followed by a return of the needle toward the zero-point, indicating a diminution in the strength of the natural current; with the cessation of the stimulation, the needle is again deflected outward to its previous position, indicating a re-establishment of the electro-motive forces. This negative variation of the current is observed equally well whether the current is conducted from the central end and the periphery stimulated, or whether the current is conducted from the peripheral end and the central stimulated. Indeed, if both ends are connected with galvanometers and the nerve stimulated in the middle, the negative variation is observed simultaneously at both ends. The excitation propagates itself, therefore, equally well in both directions.

Du Bois-Reymond, in his investigations, found that the negative variation was intimately connected with changes in the molecular condition of the nerve, and not to an escape of the current into the galvanometer circuit, nor to the establishment of an electrotonic condition, nor to an increase in the resistance of the nerve. In these respects the phenomenon is comparable to that observed in the muscle. As a further proof that the negative variation is not the result of any extraneous

electrical influence, it is only necessary to employ chemical, mechanical, or thermal agents for purposes of stimulation. Whatever the character of the exciting agent may be, provided it is sufficiently powerful, a negativity of the current is always observed. Du Bois-Reymond was also enabled to obtain a negative variation of the current in the nerves of a living frog which were yet in connection with the spinal cord. In this experiment the sciatic nerve was divided at the knee and freed from its connections up to the spinal column; the transverse and longitudinal surfaces were then placed in connection with the electrodes of the galvanometer wires and the current permitted to influence the needle. The animal was then poisoned with strychnine. Upon the appearance of the muscular spasms the needle was observed to swing backward toward the zero-point to the extent of from 1 to 4 degrees, and, upon the cessation of the spasms, to return to its previous position. In an experiment of this nature it is obvious that the negative variation was the result of a physiological stimulation of the nerve arising within the spinal cord.

The question also here arises as to whether the negative variation is due to a steady, continuous decrease of the natural current, or whether it is due to successive and rapidly-following variations in its intensity, similar to that observed in muscles. Though this cannot be demonstrated with the physiological rheoscope, as was the case with the muscle, there can be no doubt, both from experimentation and analogy, that the latter supposition is the correct one. Wedenskii (*Centralblatt für die Med. Wissenschaft*, 1883–1884) has shown that when non-polarizable electrodes connected with Siemen's telephone are placed in connection with the longitudinal and transverse sections of a nerve, low, sonorous vibrations are perceived during tetanic stimulation,—a proof that the active state of the nerve is connected with the production of discontinuous electrical currents. The oscillations of the mercurial column of the capillary electrometer also reveal similar electrical changes.

It was also shown by Bernstein (" Untersuchungen u. d. Erregungsvorgang im Nerven- und Muskelsysteme," 1871), with the repeating rheotome, that the negative variation is composed of a large number of single variations, which succeed each other in rapid succession, and summarize themselves in their effect upon the needle; that the change in the nerve which follows the stimulation propagates itself in the form of a wave, whose length has been estimated at eighteen millimetres, and whose time duration is about 0.0007 of a second. The rapidity with which the negative variation travels through the nerve of a frog is about twenty-eight metres per second.

Electrical Properties of the Uninjured Nerve.

Currents of the Resting Nerve.—The pre-existence of electrical currents in living and wholly-uninjured nerves has also been denied by Professor Hermann, who regards all portions of the nerve as iso-electrical,

any difference of potential being the result of some mechanical or chemical injury to its surface. As to whether the natural transverse section would exhibit a negativity with reference to the longitudinal surface, it is almost impossible to determine by direct experimentation, as the terminations of the nerves, both central and peripheral, are deeply imbedded in tissues, which themselves are the seat of electro-motive forces, and which cannot be distinguished, by present means of investigation, from those of the nerves. The existence of a parelectronomic layer at the periphery of the nerve which would, under certain circumstances, exhibit a positive electrical tension is, for this reason, impossible to state. The only currents thus far observed are those obtained by uniting the longitudinal and artificial transverse sections.

Action Currents.—For reasons to be stated below, it is very difficult to determine the presence of diphasic action currents during the passage of an excitatory impulse through the nerve-fibre. The so-called negative variation of the resting-nerve current,—the demarkation current,—which passes from the transverse to the longitudinal surface, and which is occasioned by tetanic stimulation, Hermann regards as the expression of an action current which flows in the nerve in an opposite direction to the natural current. The origin of this action current is to be sought for in the continuous negativity of that portion of the longitudinal surface of the nerve in contact with the diverting electrode, while the dying substance of the transverse surface takes no part in the excitation. This tetanic action current, or negative variation, was discovered by du Bois-Reymond. Bernstein also succeeded in obtaining this action current with the differential rheotome during the passage of a single excitation wave. When any two points in the longitudinal surface which exhibit no current are connected with the galvanometer and a single wave of excitation passes beneath the electrodes, it might be expected that, as in the case of the muscle, a diphasic action current would be observed, from the fact that the portions of the nerve beneath the electrodes became alternately negative with reference to all the rest of the nerve. This, however, is not the case, the absence of the two opposing phases of the action current being explained on the supposition that the negativity of the two led-off points is of equal amount, and that, owing to the great rapidity with which the excitation wave travels, the two phases fall together too closely in time to alternately influence the galvanometer needle. During stimulation of the nerve, when two currentless points are connected, there is also an absence of the action current, as was observed first by du Bois-Reymond, and which is to be explained on similar grounds. It is true that an apparent action current is sometimes seen when the stimulating current is very powerful or the seat of stimulation too near the diverting electrodes. This, however, must be attributed to an electrotonic state of the nerve.

Influence of a Constant Galvanic Current on Nerves.

In investigating the electric phenomena of nerves, du Bois-Reymond ("Untersuchungen über thierische Electricität," Bd. ii, S. 289) discovered, in 1843, that the passage of a constant galvanic current through a portion of a nerve produced a change in the electro-motive forces existing between the longitudinal and transverse surfaces, whereby the resulting nerve-current was either increased or diminished, according to the direction of the constant current. To this condition du Bois-Reymond applied the term electrotonus. It was subsequently shown by Pflüger (" Untersuchungen über die Physiologie des Electrotonus," 1859) that a definite change in the irritability of the nerve is also caused by the passage of the galvanic current, and, as it is intimately related to the change in the electro-motive forces, he applied to this alteration of excitability also the term electrotonus. This word has thus been employed to express two distinct series of effects exhibited by a nerve through a portion of which a constant galvanic current is passing. It appears desirable, for the sake of clearness, to limit the term electrotonus to the electrical or electrotonic currents which can be led off from either extremity of the nerve, and to apply to the modifications of irritability which accompany electrotonus the expression electrotonic alteration of excitability. The electrotonic currents and the associated changes in the nerve-excitability, while intimately related to each other, are, nevertheless, two distinct effects of the constant current, and can be studied independently of each other.

Electrotonus.—If a nerve be so arranged that its longitudinal and artificial transverse surfaces are connected with the terminals of the galvanometer, the deflections of the needle will indicate the usual nerve-current. The passage of the constant current through the portion of the nerve beyond the diverting electrodes will then produce a change in the strength of the nerve-current which will vary according to the direction of the experimental or " polarizing " current. If this current be transmitted through the nerve in a direction corresponding to the nerve-current, the latter will be strengthened or increased, thus constituting the positive phase of electrotonus. If the polarizing current be transmitted in the reverse direction, the natural nerve-current is weakened or decreased, thus constituting the negative phase of electrotonus. The same positive and negative phases, however, are observed when any two points on the longitudinal surface are connected with the galvanometer and the polarizing current applied to the projecting end of the nerve; the deflections of the needle indicate the existence of electrotonic currents having the same direction as the polarizing current. The natural nerve-currents have, therefore, no connection with the electrotonic currents, except in a purely accidental way, as the latter are present even when the former are entirely absent. These fundamental experiments indicate that when a constant galvanic current is flowing

through a limited portion of a nerve, all other portions exhibit the presence of electrical or electrotonic currents, which are in some way dependent upon or related to the galvanic current. The electrotonic current in the neighborhood of the positive pole, or anode, is called the anelectrotonic current, and has, in the nerve, a direction toward the polarized region. The current in the neighborhood of the negative pole, or cathode, is called the catelectrotonic current, and has, in the nerve, a direction away from the polarized region.

The electrotonic currents vary considerably in strength and extent, according to the intensity of the polarizing current, increasing steadily with the intensity of the latter without attaining a maximum so long as it is not destructive in its action upon the integrity of the nerve. The electro-motive force of these currents surpasses that of the natural currents, as shown by the method of compensation, and may amount to 0.5 Daniell. The electrotonic current is strongest in the immediate neighborhood of the electrodes, but gradually diminishes in strength as the distance between the polarized and led-off portions is increased. The distance to which the electrotonic currents extend along the nerve will depend very largely upon the strength of the polarizing current, though it is conditioned by the physical state of the nerve; for if it be ligated or injured beyond the polarized portion the current is abolished.

Other conditions being equal, the strength of the anelectrotonic current is greater than the catelectrotonic. When means are taken to increase the electro-motive force of the polarizing current, *pari passu* with the increasing resistance of the nerve both currents are increased in intensity in proportion as the polarized region is increased in extent. The electrotonic condition is established at the instant the polarizing current is closed, and disappears rapidly after it is opened, even when it is of short duration. Momentary currents, such as single induction shocks, are sufficient to develop electrotonus. The anelectrotonic current, after its origination, increases slowly, attains its maximum, and then gradually declines; the catelectrotonic current, on the contrary, attains its maximum much more quickly, and declines also more rapidly.

From the preceding statements, it is evident that the electrotonic current differs in many respects from the resting-nerve current, as well as from the action current, and is not the outcome of an excitatory state of the nerve, but that it is rather of artificial origin, connected in some way with the polarizing current. That it is not merely due, however, to an escape of the latter into the galvanometer circuit is evident from the fact that other structures, such as dead or degenerated nerves, wet threads, etc., which offer favorable conditions for the current escape, do not exhibit electrotonic currents. These facts would indicate that the phenomena of electrotonus are dependent upon the living condition of the nerve, or at least upon its anatomical integrity.

Polarizing After-Currents.—The passage of a constant galvanic current through a nerve produces an internal polarization which gives rise, upon its withdrawal, to after-currents, whose extent and direction can be determined by galvanometric observations. If the intra-polar region be connected with the galvanometer, the deflection of the needle will indicate immediately, upon the opening of the galvanic current, an after- or internal polarization current, the direction of which will depend upon the strength and time of closure of the former. When the galvanic current is strong and of short duration, the after-current is always *positive*,—that is, has the same direction as the polarizing current itself; on the contrary, the after-current is always *negative*,—that is, has a direction the reverse of the polarizing when the latter is feeble and long-continued in its action. The positive after-current is especially well developed when the direction of the galvanic current is the same as that of the propagation of the normal nerve-impulses. The presence of after-currents can also be shown in the extra-polar regions. Immediately upon the opening of the galvanic current, the deflection of the galvanometer needle indicates that the after-current in the anodic region is at first in the same but subsequently in the opposite direction to that of the anelectrotonic current, while the current in the cathodic area is always in the direction of the catelectrotonic current.

Secondary Contraction from a Nerve.—It was shown by du Bois-Reymond that when an excised nerve was laid on the sciatic nerve of a nerve-muscle preparation, stimulation of the former was always followed by contraction or even tetanus of the muscle, according as the stimulation was momentary or continuous. At first glance it might be supposed, from the analogy of secondary contraction from a muscle, that in this instance also the contraction might be due to a variation of the natural nerve-current or to an active current which would excite an impulse in the second nerve. That this is not the explanation of the contraction, however, is evident from the fact that stimulation of the nerve by any other than electrical means fails to excite a contraction. It was for this reason that du Bois-Reymond attributed the generation of the nerve-impulse in the second nerve to the development of the electrotonic condition. When the primary nerve is traversed by the electrical current, whether induced or galvanic, and passes into the electrotonic state, the secondary nerve also develops a secondary electrotonus, which persists as long as the nerve is traversed by the current. Upon the opening of the latter the secondary electrotonus also at once disappears. It is this alternate appearance and disappearance of the secondary electrotonic condition to which the excitement of the nerve giving rise to the contraction must be attributed.

A striking illustration of the production and stimulating effects of secondary electrotonus is offered by the so-called "paradoxical contraction," first observed by du Bois-Reymond ("Untersuchungen über thier-

ische Electricität," Bd. ii, S. 545). The sciatic nerve of the frog divides at the lower third of the thigh into two branches,—the tibial and the peroneal,—the former of which supplies principally the gastrocnemius and the tibialis posticus muscles. If the sciatic nerve be divided above and the peroneal nerve below the point of separation, and the latter stimulated by alternately opening and closing the constant current, the gastrocnemius at once contracts and, if the stimulation be sufficiently rapid, passes into the tetanic condition. The explanation of this contraction rests, as above mentioned, in the establishment of a secondary electrotonus.

Electrotonic Alterations of Nerve Excitability.—In addition to the electrotonic state into which the nerve passes upon the passage of a constant galvanic current through a portion of its extent, there is also produced a marked alteration in both its excitability and conductivity, whereby the results of nerve stimulation, muscular contraction, and sensation are increased or decreased, according to the strength and direction of the current.

The first accurate observations upon the alterations of the excitability were made by Valentine ("Lehrbuch der Physiologie des Menschen," 2 Auflage ii, S. 655), who discovered that the excitement aroused in a nerve experienced great difficulty in passing through the portion of the nerve traversed by the constant current, and that, if the latter were ascending, an irritant applied between it and the muscle was much less efficient in exciting muscular contractions. Eckhard (*Zeitschrift für rationale Medizin*, 2, iii, S. 198) continued and extended these observations with improved methods of research, and discovered the fact that the excitability of the nerve was always increased below the portion through which a descending current was passing He also surmised that the excitability above this portion was decreased, and, in consequence, formulated the law that the excitability is increased on the side of the cathode and decreased on the side of the anode. Pflüger finally ("Untersuchungen über die Physiologie des Electrotonus," 1859), with the aid of improved and accurate methods of investigation, enlarged our knowledge of the changes in excitability caused by the action of the galvanic current, and arranged and co-ordinated them under one general law, as follows: If any portion of a nerve be traversed by a descending or an ascending constant current, the excitability of the intra-polar as well as the extra-polar regions undergoes a change which, upon investigation, is found to be decreased in the neighborhood of the anode, or positive pole, and increased in the neighborhood of the cathode, or negative pole. The zone of diminished excitability, and to which Pflüger gave the name of anelectrotonus, extends for some distance on both sides of the anode; the zone of increased excitability, or catelectrotonus, extends in a similar manner on both sides of the cathode. These alterations of the normal excitability are most marked in the

immediate vicinity of the electrodes, but extend for some distance into both the intra- and extra- polar regions, though with gradually-diminishing intensity, until they finally disappear. Between the electrodes there is a point where the anelectrotonic and catelectrotonic states merge into each other, and at which the normal excitability of the nerve is preserved. This is known as the neutral or indifferent point. The degree to which the excitability is increased at the negative and decreased at the positive pole, and the extent to which these alterations spread themselves into both the intra- and extra- polar regions, will depend largely upon the strength of the constant current and the normal excitability of the nerve. If, while the nerve is traversed by currents of varying degrees of intensity, it be tested at all points with reference to the change in its excitability, a series of results will be obtained which can be represented graphically somewhat according to the accompanying illustration. Let the abscissa line *N N* represent the nerve, the decrease in the excitability of which is indicated by an ordinate directed downward, and the increase in excitability by an ordinate directed upward. The electrodes

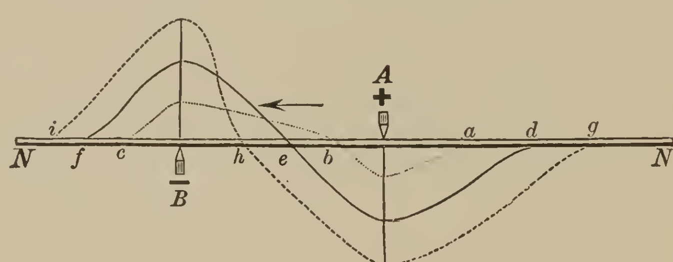

FIG. 9.

conveying the current to the nerve are represented by *A*, the positive, and *B*, the negative pole. The relative extent of the alterations of the excitability, as revealed by the energy of the muscular contraction following the application of a uniform stimulus, is shown by the three curves, the size and extent of which represent the changes produced by a weak, medium, and strong current. The curve also shows that with a weak current (*a*, *b*, *c*) the excitability in the anodal zone is decreased and in the cathodal zone increased, and that the neutral point, *b*, lies close to the side of the positive pole.

From this point the changes in the excitability gradually increase, and reach their maximum in the neighborhood of the electrodes, from which both phases gradually decline. The position of the neutral point also indicates that by far the larger portion of the intra-polar region is in the condition of increased excitability, or catelectrotonus. The curve *d*, *e*, *f*, similar in its general form to the preceding, represents the alterations in the excitability produced by a current of medium strength; *pari passu* with the increase in current-strength, there is an increase in

the amount of both anelectrotonus and catelectrotonus and the distance to which they spread themselves into the extra-polar regions. The indifferent point has advanced toward the centre of the intra-polar region, indicating that this portion of the nerve is almost equally occupied with the opposed states of excitability. The curve g, h, i represents still further the same changes following the employment of a strong current. The neutral point has now been shifted toward the cathode, and the intra-polar portion is in the condition of anelectrotonus.

The demonstration of corresponding changes in the excitability of the nerve in the intra-polar region presents many difficulties, owing to the close proximity of the electrodes conveying the polarizing and the stimulating currents and their consequent interference with each other. Pflüger overcame this difficulty by employing as the testing agent a concentrated solution of salt, and succeeded in demonstrating the above-mentioned intra-polar changes. From this fact it is clear that the changes in the excitability are not dependent upon or related to the special nature of the electrical stimulus, as they exhibit themselves upon the application of all forms of stimuli, whether chemical, mechanical, or thermal.

In order that the opposed electrotonic conditions of the nerve may correspond with the direction of the electrotonic currents, the region $A\ g$ (Fig. 9) is designated as that of extra-polar descending anelectrotonus, and the region $B\ i$ as that of extra-polar ascending catelectrotonus, when g represents the central and i the peripheral end of a motor nerve. When the conditions are reversed, however,—that is, when i is the central and g the peripheral end,—then the region $A\ g$ is termed that of the extra-polar ascending anelectrotonus, and the region $B\ i$ as that of descending catelectrotonus. The conditions of ascending catelectrotonus and anelectrotonus cannot, without much difficulty, be directly proved, owing to the fact that the excitement following an irritation applied to the ascending regions must traverse the portion of the nerve through which the constant current is passing, as well as through the portion which is already in the opposite electrical condition. The conductivity of the nerve appears to be impaired in the neighborhood of the anode,—a condition which increases with the decrease in the normal excitability. On the contrary, the excitation originating in the descending catelectrotonic and anelectrotonic regions passes directly, without interference, into the muscle. Hence it is that only in these regions can the law of the electrotonic changes in the excitability be successfully demonstrated.

The excitability of the nerve which has been altered in the manner related above, during the passage of the constant current, undergoes yet further modifications immediately upon the opening of the current. The normal condition is not at once re-established, this being regained only after the lapse of some minutes, especially if the current has been strong and of long duration. These after-results of the action of the

constant current have been carefully investigated by Pflüger, who has termed the increase of excitability the positive modification, the decrease of excitability the negative modification. If, for example, the nerve be examined with reference to these changes, it will be found that the excitability in the region of the anode will undergo a positive modification which lasts for a few seconds only, after which it returns to the normal condition. In the region of the cathode the excitability passes in a similar manner for a few seconds into a negative phase, after which it again undergoes a continuous positive modification which may last for a variable length of time. Its duration appears to be a function of the current-strength, for, with feeble currents, it lasts from one to two minutes, with strong currents from ten to fifteen minutes. The opening of the constant current very frequently produces in the nerve such a change in its excitability that a series of pulsations or an apparent tetanus follows, which has long been spoken of as the opening tetanus of Ritter.

The Law of Contraction.—The general law of electrical stimulation was first accurately formulated by du Bois-Reymond in 1845, in the following words: "It is not the absolute value of the current density at any moment to which the motor nerve reacts, as shown by the contraction of its related muscle, but the change of this value from one moment to another; the stimulus to the contraction which follows these changes is the more considerable the more rapidly they follow each other, or the greater they are in any unit of time." From this law it follows that the mere passage of a constant current through a nerve does not, in general, excite it to activity, this being accomplished only by a change in the current-strength. These variations, however, must occur with a certain rapidity, otherwise even the strongest currents have no appreciable effect when they are very gradually increased or diminished. The sudden variation of a weak current is often very effective in the stimulation of a nerve. The exact law, however, of the dependence of stimulation upon variations in current-strength has not yet been definitely stated, but it is probable that within certain limits the sought-for function consists in a simple proportionality.

There are certain facts which appear, however, to contradict the general law just mentioned. With regard to the centripetal nerves, it is well known that, independent of the sensations which occur upon the opening and closing of the circuit, the constant flow of the current also gives rise to persistent sensations, which may become unbearable. But, as Professor Hermann remarks, an exact analysis of these phenomena shows that the sensory end organs, as well as the sensory central organs, are not sufficiently excluded to justify a change in the general law, as the end organs are so constituted that they are stimulated not only by variations, but also by constant conditions. With regard to centrifugal nerves, it was observed by du Bois-Reymond that tetanizing effects occa-

sionally follow the passage of very strong currents; and, as they continue after the cessation of the current, he attributed them to an electrolytic change in the nerve. It was subsequently shown by Pflüger, however, that weak constant currents also had a tetanizing effect, even when all polarization of the electrodes was carefully excluded. He assumes, therefore, that the nerve is stimulated by the steady flow of the current, as well as by variations in its strength, and that probably the stimuli proceed from the cathode. If the constant current is capable of developing stimuli, it must be assumed either that they are very weak, as compared with those produced by a sudden variation in the strength, or that their character is such that not every organ is capable of responding to them.

The law of contraction, which expresses the effects in a motor nerve which follow the closure and opening of the constant current, has been established by the observations of many physiologists. Pfaff made the discovery, in 1793, that for the occurrence of a closing or an opening contraction it was not a matter of indifference whether the current in the nerve was ascending or descending in its direction. Ritter, in 1798–1805, made an elaborate series of experiments, the chief merit of which was the discovery of the influence which the excitability of the never has upon the law of contraction. In 1829 Nobili stated clearly, for the first time, the law of contraction free from Ritter's theory of a contrast between flexors and extensors. This was confirmed by du Bois-Reymond in his classic investigations, and later by Heidenhain, who, in addition, first determined the influence of the intensity of the current upon the results obtained. Corresponding, in many respects, to the law of contraction as stated by previous observers, is that of Pflüger's, as follows:—

Current Intensity.	Ascending Current.		Descending Current.	
	Closing.	Opening.	Closing.	Opening.
Weak	Contraction.	Rest.	Contraction.	Rest.
Medium	Contraction.	Contraction.	Contraction.	Contraction.
Strong	Rest.	Contraction.	Contraction.	Rest or weak contraction.

Pflüger attempted to explain all the phenomena of the above law of contraction on the assumption that the current stimulates the nerve only at the one electrode, at the cathode in closing, and at the anode in opening, or, in other words, by the appearance of catelectrotonus or by the disappearance of anelectrotonus,—not, however, by the opposite changes. He further assumes that the appearance of catelectrotonus is more effective in exciting the nerve than the disappearance of anelectrotonus. The law

of contraction can, then, be explained as follows: Very feeble currents, either ascending or descending, produce contraction only upon the closure of the circuit, the sudden increase of the excitability in the catelectrotonic area being alone sufficient to generate an impulse. The contraction which follows the closing of the ascending current depends upon the fact that the decrease of excitability at the anode is insufficient to interefere with the conduction of the cathodal stimulus. Medium currents, either ascending or descending, produce contraction both in closing and opening the circuit. The appearance of catelectrotonus and the disappearance of anelectrotonus are both sufficiently powerful to generate an impulse without, however, impairing the conductivity of the nerve.

Very strong currents produce contraction only upon the opening of the ascending and closure of the descending currents, or upon the passage of the excitability in the former from the marked anelectrotonic decrease to the normal condition, and in the latter from the normal to that of catelectrotonic increase, the absence of contraction upon the closure of the ascending current being dependent upon the blocking of the cathodal stimulus by the decrease of the excitability at the anode. With the opening of the descending current the disappearance of anelectrotonus should also be followed by contraction, which would indeed be the case if the stimulus so generated was not blocked by the sudden decrease of the conductivity at the cathode.

Nothing analogous to the law of contraction has as yet been observed in secretory nerves, but Donders confirmed it in his experiments upon the inhibitory fibres of the vagus.

Experiments on Man.—The preceding statements as to changes in the excitability produced by a constant current, as well as to the law of contraction, are based entirely upon experiments made on the isolated nerve of the frog, and under what may be regarded as abnormal conditions. It is not to be expected, therefore, that the results which have been obtained by the application in the same manner of a constant current over the course of a human nerve, surrounded by tissues possessed of different degrees of resistance, would strictly correspond to those obtained by purely physiological methods. Nevertheless, when rightly applied, the physiological effects of the constant current on the normal human nerves, though differing somewhat in detail, are the same in principle, and confirm Pflüger's laws.

Eulenburg (*Deutsches Archiv für klinische Medicin*, Bd. iii, S. 117, 1867), in his investigations of the electrotonic effects of the constant current applied percutaneously in man, found Pflüger's law confirmed, and stated his results in the following words: "There can be no doubt that, by the percutaneous application of stable galvanic currents of moderate intensity, we can succeed in producing phenomena in superficially-lying motor nerves which agree very well with those of the descending extra-polar anelectrotonus and descending extra-polar catelec-

trotonus,—*i.e.*, in producing in the first case a negative and in the second a positive increment of the excitability of that part of the nerve lying behind the current. He admitted, however, that differences sometimes occurred, and attributed them to the influence of the undisturbed nutrition of the nerve, and to central innervation modifying the electrotonic excitability. Erb (*Deutsches Archiv für klin. Med.*, Band iii, S. 238, 513, 1867), however, found, as a constant result of many experiments, performed according to the usual physiological methods, that there occurs a diminution of the excitability in the extra-polar catelectrotonic region and an increase in the extra-polar anelectrotonic region, as shown by stimulation with the induced current.

Helmholtz subsequently suggested that the cause of the deviation from Pflüger's law might be the position of the nerve in the uninjured body. As the nerve is in relation with a relatively large amount of well-conducting tissue, the current density must quickly decrease with the distance from the electrodes; whilst, of course, under the polarizing electrode, the current density in the nerve is the greatest; this density, on account of the moist conductors surrounding the nerve, so rapidly decreases that it becomes almost *nil* for the nerve at even a small distance from the electrodes. At a short distance, therefore, from the positive pole the density is so slight that it may be assumed without error that the current now leaves the nerve, or, in other words, that the cathode is to be found at this point. It is to be expected, therefore, that the effects of the opposite pole would be observed only at a short distance from the applied pole. As Erb did not apply the exciting electrode near enough to the polarizing electrode, he obtained, not far from the anode, the phenomena of normal catelectrotonus, and from the cathode those of normal anelectrotonus. Acting on the suggestion of Helmholtz, Erb so arranged the electrodes that the polarizing and exciting currents could be applied either simultaneously or consecutively to the same tract of nerve. By this method of investigation he obtained results which harmonized in the most complete manner with those of physiological experiment, viz., increase of excitability in the catelectrotonic and decrease of excitability in the anelectrotonic regions.

The changes in the excitability of a nerve of a living man and the contractions which follow the closing and opening of the constant current have been thoroughly studied by Waller and de Watteville ("Physiological Transactions of the Royal Society, 1882"). These observers employed a method similar to that of Erb, conjoining in one circuit the testing and polarizing currents. By the graphic method they recorded first the contraction produced by an induction shock alone; and, secondly, the contraction produced by the same stimulus under the influence of the polarizing current. As a result of many experiments, they also demonstrated an increase of the excitability in the polar region when it is cathodic, and a decrease when it is anodic. Following the suggestion

of Helmholtz, that the current density quickly decreases with the distance from the electrodes, they recognize, at the point of entrance and exit of the current from the nerve, two regions,—a polar, having the same sign as the electrode, and a peripolar, having the opposite sign. (See Figs. 10 and 11.) The peripolar regions also experience similar alterations of excitability, though less in degree, according ast hey are cathodic or anodic.

As it is impossible to confine the current to the trunk of the nerve when surrounded by living tissues, as is easily the case when experimenting with the frog's nerves, it is incorrect to speak of either ascending or descending currents. Waller ("Human Physiology," p. 363, 1891), who has thoroughly studied the electrotonic effects of the galvanic current from this point of view, sums up his conclusions in the following words: "We must apply one electrode only to the nerve and attend to its effects alone, completing the circuit through a second electrode, which is applied according to convenience to some other part of the body.

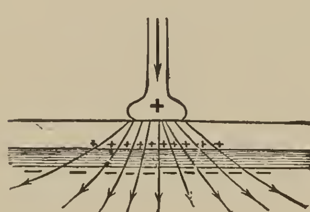

Fig. 10.—Anode of Battery.
Polar region of nerve is anodic. Peripolar region of nerve is cathodic.

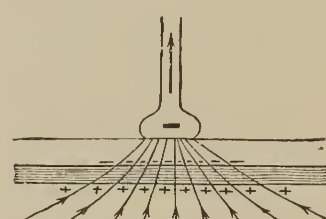

Fig. 11.—Cathode of Battery.
Polar region of nerve is cathodic. Peripolar region of nerve is anodic.

"Confining our attention to the first electrode, let us see what will happen according as it is *anode* or *cathode* of a galvanic current, Figs. 10 and 11. If this electrode be the anode of a current, the latter enters the nerve by a series of points and leaves it by a second series of points; the former, or proximal series of points, collectively constitutes the *polar* zone or region; the latter, or distal series of points, collectively constitutes the *peripolar* zone or region. In such case the polar region is the seat of entrance of current into the nerve,—*i.e.*, is *anodic;* the peripolar region is the seat of exit of current from the nerve,—*i.e.*, is *cathodic.* If, on the contrary, the electrode under observation be the cathode of a current, the latter enters the nerve by a series of points which collectively constitute a 'peripolar' region, and it leaves the nerve by a series of points which collectively constitute a 'polar' region. The current, at its entrance into the body, diffuses widely, and at its exit it concentrates; its 'density' is greatest close to the electrode, and, the greater the distance of any point from the electrode, the less the current density at that point; hence it is obvious that the current density is greater in the polar than in the peripolar region. These conditions having been recognized, we

may apply to them the principles learned by study of frogs' nerves under simpler conditions. Seeing that, with either pole of the battery, whether anode or cathode, the nerve has in each case points of entrance (constituting a collective anode) and points of exit to the current (constituting a collective cathode), and admitting as proved that make excitation is cathodic, break excitation anodic, we may, with a sufficiently-strong current, expect to obtain a contraction at make and at break with either anode or cathode applied to the nerve, and we do so in fact. When the cathode is applied, and the current is made and broken, we obtain a *cathodic make contraction* and a *cathodic break contraction;* when the anode is applied, and the current is made and broken, we obtain an *anodic make contraction* and an *anodic break contraction.* These four contractions are, however, of very different strengths; the cathodic make contraction is by far the strongest; the cathodic break contraction is by far the weakest; the cathodic make contraction is stronger than the anodic make contraction; the anodic break contraction is stronger than the cathodic break contraction. Or, otherwise regarded, if, instead of comparing the contractions obtained with a sufficiently-strong current, we observe the order of their appearance with currents gradually increased from weak to strong, we shall find that the cathodic make contraction appears first, that the cathodic break contraction appears last, and the formula of contraction for man reads as follows :—

"Weak current	K. C. C.			
Medium current......	K. C. C.	A. C. C.	A. O. C.	
Strong current........	K. C. C.	A. C. C.	A. O. C.	K. O. C.

"That such should be the normal order of appearance is fully accounted for by the following considerations :—

In the	The Nature of Stimulus is	The Situation of Stimulus is	
K. C. C.	Cathodic	Polar	= Best stimulus in best region ;
A. C. C.	Cathodic	Peripolar	= Best stimulus in worst region ;
A. O. C.	Anodic	Polar	= Worst stimulus in best region ;
K. O. C.	Anodic	Peripolar	= Worst stimulus in worst region ;

which also account for an apparent anomaly, viz., that sometimes the anodic closure contraction precedes the anodic opening contraction, while sometimes this order is reversed. This difference depends upon relative current densities in the two regions, which are determined by the nature of the tissues by which the nerve is surrounded."

Theories of the Electrical Phenomena of Nerves.

The Molecular Theory.—In explanation of the origin of the currents in nerves obtained by uniting the longitudinal and artificial transverse surfaces, du Bois-Reymond assumed, as in the case of muscle, the existence of electro-motive molecules, arranged one behind the other and imbedded in an indifferent conducting medium. These molecules are

supposed to have their positive poles directed toward the longitudinal, their negative poles toward the transverse surfaces. This scheme accounts for the existence of strong but not for weak currents, unless the further assumption be made that the electro-motive force of the molecules diminishes with varying rapidity from the equator. The negative variation of the nerve-current is accounted for on the assumption that the electro-motive force, during the state of excitation, is diminished, or that the molecules themselves become differently arranged, whereby their electro-motive forces become less evident.

The electrotonic currents are explained on the assumption that the molecules have the peripolar arrangement, but are capable of being separated and rotated by the polarizing current. When the current is applied to the nerve, the peripolar molecules become dipolar, and their position becomes such that their negative surfaces are turned toward the positive pole and their positive surfaces toward the negative pole. The molecules thus more or less reversed, according to the strength of the polarizing current, discharge their individual currents in the same direction as the polarizing current, and thus give rise to the electrotonic current. The gradual diminution in the strength of the electrotonic currents in the extra-polar regions is explained on the assumption that the normal tendency of the molecules to maintain their peripolar arrangement gradually asserts itself and resists, in proportion to their distances from the electrodes, the reversing action of the polarizing current.

The Alteration Theory.—According to Hermann, the currents obtained from nerves are not natural, but artificial. When uninjured and in a condition of rest, the nerve is devoid of electrical properties. In order to obtain a current, it is necessary to make a transverse section of the nerve, whereby the cut surface undergoes disorganization and becomes negative to the living substance. The electro-motive forces which then make their appearance at the line of separation between the dead and living tissue—the so-called demarkation surface—give rise to the current which has been termed the demarkation current. The so-called negative variation of the nerve-current Hermann regards as an action current, the result of an electrical opposition between the excited (negative) and the resting (positive) portion of the nerve. Hermann's conclusions as to the origin of the electrical currents in living protoplasm are stated on page 26.

An explanation of the electrotonic currents is based upon an experiment of Matteucci's, who discovered that, if a wire be surrounded with a moist conductor and brought into connection with the electrodes conveying a constant current, additional currents are developed, which are similar to the electrotonic currents of nerves, and which are due to polarization. Hermann subjected these phenomena to a further investigation, and found a yet more striking analogy, which he explained as follows: The current conducted to the sheath tends to equalize itself in

the well-conducting metallic core; but as polarization takes place between the sheath and core, a counter-resistance is established which, adding itself to the ordinary transition resistance, causes the current to escape in longitudinal loops, the extent of which is proportional to the degree of polarization. Electrodes applied to the extra-polar regions will send off parts of these currents, which will have, as shown by the galvanometer, the same direction as the polarizing or constant current. The anatomical structure of the nerve bears some resemblance to the metallic core and its sheath. While there may not be the same difference in conductivity between the nerve-sheath and its axis-cylinder as in the former instance, the fact that the transverse resistance of a living nerve to the passage of a galvanic current is about five times as great as the longitudinal resistance would support the view that the electrotonic condition of the nerve also is developed in consequence of an internal polarization. The internal polarization, moreover, is a property of living nerve-fibre only, as it is entirely absent in the dead fibre. The electrotonic currents are, therefore, due to an escape of the polarizing current.

ELECTRO-DIAGNOSIS.

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Electro-diagnosis is a subject of great importance in many respects, but so difficult and complicated that it is very apt to be neglected in the general study of electro-therapeutics. It may be truthfully said that more knowledge is required to make a correct diagnosis by means of electricity than to use it successfully in the treatment of the case. By its use, however, we often get a knowledge of the probable duration and curability of certain diseases which we never could obtain in any other way.

First of all, it is very important that the instruments used should be carefully constructed and accurately calibrated, so that the results obtained should be as accurate as possible. It is extremely desirable that standard instruments should be adopted, so that different observers can compare the results obtained; but, unfortunately, these do not exist at present. At the Electrical Congress held at Paris in 1881 a standard faradic machine was adopted. In this machine the galvanic generator is a single Daniell cell. The various parts of the machine are as follow:

	Primary Coil.		Secondary Coil.	
Length of spool (excluding wooden frame), .	88	millimetres	65	millimetres.
Diameter of spool, ...	36	"	68	"
Diameter of wire, ...	1	"	0.25	"
Number of turns of wire, ...	300	"	5000	"
Layers of wire, ...	4	"	28	"

Resistance, primary coil, about 1.5 Siemens units; secondary coil about 300 Siemens units. Were this machine adopted as a standard for the whole scientific world, and if all our leading makers would adhere rigidly to these dimensions in making faradic coils, then different observers could compare their results with each other. At present, however, there are just as many faradic coils in use as there are makers of electric apparatus, and, therefore, all quantitative comparison is impossible, except between those who happen to possess instruments made by the same manufacturer.

At a recent meeting of the American Electro-Therapeutic Association, held in New York City, committees were appointed to consider the choice and adoption of a standard faradic coil and a milliampèremeter. It is to be hoped that by another year we shall have the standard available for use. It is hardly necessary to say that the use of carefully-standardized instruments, which will enable all who use them to compare

their results, will be of great value to the science of electro-therapeutics. Delicate instruments are very apt to get out of order, and in all large cities there should be standards available to which physicians could bring their instruments at frequent intervals for comparison and correction.

By far the most important branch of this subject is the electrical examination of motor nerves and muscles. This is done in the following manner: Of the two electrodes to be used, one is called the indifferent electrode, and consists of a flat sponge with a metal backing. It is of little consequence where this is placed; but its position is generally the sternum, on account of its convenience and the flat surface which it offers for good contact. The other electrode, which is to be applied to the nerve or muscle, is very much smaller than the former.

Erb recommends an electrode exactly ten square centimetres in surface (the so-called "normal electrode"), so that the density of the current may be accurately calculated. The source of error, however, is in the fact that, although we can calculate with a good deal of certainty the amount of current entering the skin, it is almost impossible to tell what proportion of this enters the nerve which we wish to act upon. It is just this error which forms one of the greatest obstacles to obtaining accurate results in this method.

The conductivity of the skin and subjacent tissues depends upon the amount of moisture they contain, which, of course, may vary from day to day. It is on this account that with the same electrode and the same current a less amount of electricity will reach the nerve at one time than at another, which, of course, will modify the result.

Still another source of error is the variation, both in temperature and in amount, of the water contained in the electrodes themselves. This last error may be minimized by careful attention on the part of the operator.

In order to find the density of the faradic current, the coil-distance in millimetres should be divided by the area of the active electrode in square centimetres. Thus, if the normal electrode of Erb be used, the equation would read:—

$$D = \frac{x \text{ mm. C. D.}}{10^2 \text{ cm.}}$$

If, in place of this electrode, the so-called "unit electrode" of Stintzing be used, the equation would read:—

$$D = \frac{x \text{ mm. C. D.}}{3^2 \text{ cm.}}$$

In view of the fact that it is impossible to tell how much of the electricity enters the nerve, or, in other words, how much of the active electrode is active, this calculation may be dispensed with in the preparation of a practical table for clinical use. In this case the record is kept

simply in terms of the coil-distance. Owing to the lack of standard instruments, it is absolutely necessary for every observer to make his own record for clinical use, and, whenever he makes a test, he must use the same instruments and electrodes that were then employed.

There are, unfortunately, two methods of marking faradic coils, which help to make this much mixed-up subject still more chaotic. One is to have the scale read zero when the two coils are completely closed, and when the current is, therefore, at a maximum. The other—and, in the author's opinion, far more rational method—is to have the scale read zero when the current is at zero.

The writer would offer the following substitute for the present method of notation, which seems to him much simpler and more rational than those now in use: instead of noting the coil-distance in centimetres, to discard the term entirely, and have the scale divided into one hundred equal divisions, to be called degrees of current. When the primary coil is completely uncovered, both the current and the scale are at zero. When the two coils are pushed completely together, one hundred degrees of current are obtained, or the maximum. The coil employed by the writer is marked in this way, and an extensive use of it proves the method to be quite satisfactory.

The following table, showing the average faradic irritability, is from Stintzing:—

Nerve.	C. D. Stintzing.	C. D. American Scale.
Spinal accessory	137.5	12.5
Musculo-cutaneous	135.	15.
Mental branch of facial	132.5	17.5
Ulnar (above olecranon)	130.	20.
Frontal branch of facial	128.5	22.5
Median	122.5	27.5
Facial (main trunk)	121.	29.
Ulnar (at olecranon)	118.5	31.5
Peroneal	115.	35.
Crural	111.5	38.5
Tibial	107.5	42.5
Radial	105.	45.

In this table the figures under the column marked Stintzing show the coil-distance in the scale where 0 C. D. = maximum current. The second column contains the readings of the scale where 0 C. D. = 0 current. In both cases the length of the scale equals one hundred and fifty millimetres.

When testing for faradic irritability, the negative pole of the secondary coil should always be used, since the results vary slightly, according to the pole employed. In testing the galvanic irritability, the same electrodes are used as with faradism.

The instrument used to indicate the amount of current is the milli-

ampèremeter, or milliammeter, of which a different one is made by each manufacturer of electrical apparatus, most of them having defects more or less glaring, either in their adaptation to medical uses or in calibration. They are all supposed to be divided according to the same unit, the milliampère, but there is so much variation between the different instruments that comparison between the results obtained by different men is very far from satisfactory.

Normal Reaction of Nerves and Muscles.

In testing the irritability of nerves and muscles by means of the faradic current the negative pole of the current from the secondary coil is always used, in order that the results may be uniform. The contraction would vary slightly according to the pole used, but the faradic current is not employed in the study of these variations. The galvanic current, being the more constant, is the one used exclusively for this purpose. The irritability may vary in four different ways, forming what is called the normal formula of contraction. If the negative pole be applied to the peroneal nerve, and an electric current sent through it, a contraction will occur,—the strongest obtainable from this current. It is called the cathodal closing contraction (Ca. Cl. C.). If we now apply the anode, or positive pole, to the same spot and close the current, we obtain the next strongest contraction, called the anodal closing contraction (An. Cl. C.). If this current be now broken or opened, we have a still weaker response from the muscles known as anodal opening contraction (An. O. C.). Finally, if we apply the negative pole again and open the current, we shall have the weakest contraction of all,—cathodal opening contraction (Ca. O. C.).

The following table, prepared by Luvandowski, exhibits the formula for three nerves. The figures in the columns denote the amount of current, expressed in milliampères, required to cause contraction of the muscles which the nerves supply. The testing electrode had a superficial area of ten square centimetres,—the "normal electrode" of Erb :—

	Ulnar Nerve.	Radial Nerve.	Median Nerve.
Ca. Cl. C.	1.0	1.8	0.8
An. O. C.	2.5	3.7	1.0
An. Cl. C.	1.3	3.5	0.9
Ca. Te.	4.3	7.8	4.0
Ca. O. C.	4.9	9.0	6.0

It is to be understood that the contractions produced are just sufficient to be distinctly visible to the eye. The greatest care must be used to have the active electrode accurately localized upon the part whose reaction it is desired to test. The only way this can be accomplished is thorough anatomical knowledge of the parts, combined with skill and

experience in the use of the method. Another rule of value to follow is: always use the same method and keep to the same order in making these examinations. If this is done and the same instruments are used, with the same electrodes soaked to the same degree with water at the same temperature, then the results obtained should be susceptible of comparison with others, and be able to give us valuable information as to the healthy or diseased condition of the parts. In making these examinations it must be borne in mind that the electric stimulus is very fatiguing to nerves and muscles, and therefore, if the same part be examined too often, the final result may be deceiving.

Changes in Electrical Irritability.

The electrical irritability of nerves and muscles may differ in two ways; that is, either in quantity or quality. As to quantity, it may be either increased or diminished. Increased irritability means that a smaller amount of current is required to produce contraction than under normal conditions. This condition is met with in tabes dorsalis and tetany. Diminished irritability is just the reverse of the former condition. It is found in many affections of the motor apparatus, as myelitis, spastic paralysis, multiple sclerosis, brain-tumors, multiple neuritis, writers' cramp, etc.

Increased or diminished irritability is generally the same for both currents. Cases are occasionally found, however, where one is increased and the other diminished. Where single groups of nerves are affected, or where the disease is confined to one side of the body, as in cases of hemiplegia, the well side should always be examined first, and then the affected side. In this manner variations from the normal are readily detected. Where the affection is bilateral it is more difficult to arrive at a satisfactory result for lack of any part of the individual to be used for comparison. They may be compared with the average normal irritability which the experimenter has found out by previous observations, and this is the ordinary method of procedure.

Another plan has been devised by Erb, which it is well to be acquainted with. It may be of use on occasion, in order to verify the results obtained in the ordinary way. It consists in determining the irritability of four nerves in different parts of the body, and thus finding out their relative value. He lays great stress upon the importance of first finding out the relative resistance of the parts, for upon this depends the amount of electricity which enters the body, and therefore the degree of contraction produced.

Every change in the relative value of the resistance of the parts has a direct effect upon the importance to be given to the results obtained in testing the irritability. Suppose, for example, that in a certain case both peroneal nerves were found to be affected by currents much weaker than ordinary. If the resistance was normal, this would show that the

irritability of these nerves was increased. If the resistance of the parts was found to be greater than normal, it would indicate that the irritability of these nerves was even greater than was at first supposed. If, on the contrary, the resistance was less than normal, it would account for the apparent increase in the irritability, and might lead to the conclusion that it was really no greater than it should be.

In making these examinations the following four nerves should be chosen: The frontal branch of the facial nerve,—*i.e.*, that which supplies the frontalis and corrugator muscles; the spinal accessory, which supplies the trapezius muscle; the ulnar nerve in the arm above the elbow; and the peroneal nerve in the leg just above the căpitellum fibulæ. By means of a fine electrode these four points are carefully sought out, and with the negative pole of the faradic current contractions are obtained at each of them, and the results noted in coil-distance. The galvanic current is now made use of, and the amount of current which a fixed number of cells (10 to 12) would give at each of the four points is also noted. The same apparatus is used throughout the examination, and the same method employed; that is, the negative pole is used for the active electrode, while the positive pole rests upon the sternum.

The following tables are examples of what has just been described. The figures in the first two columns express the irritability of the nerves on the two sides of the body. Those in the last two columns show the amount of current which a constant electromotive force (10 cells) gives at each of the four points of application. They express, therefore, the relative amount of resistance at these points:—

1. Healthy man, aged 38; artisan.

	Coil-Distance in Millimetres. Minimum Contraction.		Deflection of Galvanometer with 10 cells. C. R., 150.	
Frontal nerve	Right, 165	Left, 166	Right, 18°	Left, 19°
Spinal accessory	" 172	" 177	" 16°	" 15°
Ulnar nerve	" 150	" 158	" 6°	" 6°
Peroneal nerve	" 160	" 163	" 7°	" 9°

2. Healthy man, aged 24; laborer.

Frontal nerve	Right, 195	Left, 192	Right, 17°	Left, 17°
Spinal accessory	" 187	" 182	" 10°	" 9°
Ulnar nerve	" 175	" 185	" 6°	" 10°
Peroneal nerve	" 180	" 180	" 5°	" 5°

It is to be observed that the force of the galvanic current in these tables is noted not in milliampères, but in the degrees of the scale of an ordinary galvanometer. The difference between a galvanometer and a milliampèremeter is that in the former instrument the degrees are arbitrary gradations, while in the latter they represent the now universally

recognized unit of quantity,—the milliampère. This is of little consequence, however, since it is not the absolute values that are desired here so much as the relation between them.

It has been found, from numerous observations of this kind, that the reactions for the two sides of the body are almost exactly the same. The reactions of the ulnar and peroneal nerves are also very similar, while the frontal nerve shows itself a little less sensitive and the accessorius a little more sensitive. The great importance of these three data lies in the fact that, being simply expressions of relative value, they are just as true for one instrument as for another, and may be made use of when testing the irritability of the nerves, without regard to the apparatus employed.

Qualitative Changes in Electrical Irritability.

The irritability of nerves and muscles may be increased or diminished, as already described; but, in addition, we may also have changes in the character of the contractions produced. These changes, taken together, are known as the reaction of degeneration.

Reaction of Degeneration.

It should be explained just here, for the sake of clearness, that in certain old cases of paralysis—as, for example, the facial and also the infantile form—there is absolute degeneration of both nerve and muscle; that is to say, these parts lose their characteristic structure and become simple bands of fibrous tissue, which, of course, give no reaction either to the faradic or galvanic currents. This absence of reaction has nothing to do with the so-called reaction of degeneration. The typical form of the reaction of degeneration occurs about as follows: After a slight increase in the electrical irritability, there begins a decrease of the same in the affected nerve until about the end of the second week, when it completely disappears, both for the faradic and galvanic currents. All voluntary movements are now impossible.

As to the muscles supplied by the affected nerve, their irritability to the faradic current is gradually lost, but to the galvanic current it slowly increases. In certain cases the irritability to the galvanic current is so greatly increased that contractions are produced by the electrical irritation of the well side. The mechanical irritability of the muscles is also increased so that a light tip with the end of a lead-pencil will often cause them to contract.

The most characteristic sign of the reaction of degeneration is what is known as the "sluggish contraction" (träge zuckung). When galvanism is applied to a healthy muscle, the resulting contraction is as quick as lightning (blitzartige). When the reaction of degeneration is present, however, the galvanic current, even if strong, never produces the

lightning-like contraction of health, but, in its place, a slow, lazy contraction. Changes in the normal formula of contraction also occur early in the process of degeneration. The An. Cl. C. gradually increases in strength, and may even become finally stronger than the Ca. Cl. C. The Ca. O. C. also increases in strength. After a few weeks, the increased galvanic irritability disappears, while the changes in the formula and the sluggish contractions remain.

The first sign of regeneration in the affected nerves and muscles is the return of the muscular tone, whereby they are seen to hold their own better against the constant pull of the antagonizing muscles. Voluntary motion next becomes possible, though the muscles are very weak and soon tire out. Then the nerve itself becomes susceptible to electrical stimulus, although it remains for a long time below the normal irritability. Finally, abnormalities in the formula of contraction disappear from the muscles, along with the sluggish contractions.

The pathological changes occurring in the muscles and nerves which exhibit the reaction of degeneration are as follow: In the early days of the process the medullary sheath undergoes granular degeneration. The axis-cylinder softens down to a homogeneous protoplasmic mass, and the nuclei in the white substance of Schwann proliferate. There is formed a large amount of new connective tissue, which grows into the nervous matter in all directions, and finally produces a regular cirrhosis of the nerves. At the point of injury to the nerve, if there has been one, a circumscribed traumatic neuritis occurs. The regeneration takes place by means of trophic influences. First the seat of injury is bridged over by what might be called a sort of protoplasmic callus. The repair of the nerve begins at the periphery. The pale, narrow bands which represent the nerve-fibres gradually surround themselves with a medullary sheath, and the continuity of the separate fibres is restored. The newly-formed interstitial connective tissue remains permanent, however. The muscular fibrillæ undergo simple degeneration, or, at most, there is but a small amount of adipose formation.

If regeneration does not take place, there may be complete disappearance of the muscular tissue. The muscular nuclei increase, and collections of cells form in the interstitial connective tissue, which lead to hyperplasia and cirrhosis of the same. In incurable cases the muscle is reduced to a thin, fibrous cord, with only here and there traces of muscular tissue. The processes of degeneration in the nerve and the interruption of continuity explain quite satisfactorily the various phenomena as seen. It must be said, however, that, as regards certain details, it is to a great degree speculation. The increased irritability of the muscles to the galvanic current is owing, according to Gessler, to irritative processes within the sarcolemma. The rapid loss of faradic irritability of the muscles, as well as the change of the normal formula of contraction, is due to chemical changes in the muscle. The decrease

of the galvanic irritability, later in the course of the disease, is due to the progressive increase in the muscular atrophy.

Atypical Forms of the Reaction of Degeneration.

It must not be supposed that all forms of degeneration follow the typical course just described. Between normal reaction of nerve and muscle and fully-developed reaction of degeneration we may have all degrees of change. Stintzing divides the reaction of degeneration into four different grades, as follows: 1. Highest grade. Reaction of degeneration, with total loss of irritability of the nerve. Seen in peripheral paralysis, chronic poliomyelitis, and progressive bulbar paralysis. 2. High grade. Reaction of degeneration, with partial irritability of the nerve. Seen in peripheral paralysis. 3. Middle grade. Reaction of degeneration, without loss of irritability, but with sluggish contractions to both currents. Seen in peripheral paralysis, chronic poliomyelitis, and after nerve-stretching. 4. Lower grade. Reaction of degeneration, with prompt contraction from electric irritation of the nerve (partial reaction of degeneration). Seen in peripheral and diphtheritic paralysis, progressive bulbar paralysis, and atrophic spinal paralysis; also after nerve-stretching.

These four principal groups do not exhaust all the varieties and modifications of this condition. The same nerve-trunk may present complete reaction of degeneration in one part of its course and the partial form in another portion. Partial reaction of degeneration may be found in a nerve, and later on in the course of the disease the degeneration may become complete. Finally, the galvanic current may produce a prompt reaction, while the faradic current causes sluggish contractions.

As to the muscles, there are certain peculiar cases where one part of a muscle is degenerated, another portion still further degenerated, while still other portions may have escaped entirely. Such cases present a diminished irritability of the nerve to both currents, while the muscle itself shows every possible variation, both in the form and intensity of the contractions produced.

The Electric Reaction of Myotonia Congenita.

As is well known, this disease consists in a remarkable stiffness and rigidity of the muscles after rest. With continued motion the limbs gradually regain their normal flexibility. Energetic contraction of a muscle produces a condition of tonic spasm, lasting from ten to thirty seconds. In these cases the nerves show a normal reaction to both the faradic and galvanic currents. It is very different with the muscles, for they exhibit to both currents a greatly-increased irritability. Even moderate faradic currents produce a continuous muscular contraction.

If the galvanic current be used, there is observed a remarkable sluggishness and duration of the contractions produced. These contractions often have the result of causing deep hollows or ridges in the muscles, with corresponding slow movements of the limbs. If the current be allowed to flow stabile through a muscle, a remarkable phenomenon occurs. There arise regular rhythmical contractions, which start from the negative pole and travel toward the positive. This phenomenon is best produced when the electrode is placed not directly upon the muscle itself, but in the immediate neighborhood of its point of insertion. These contractions may occur in any of the voluntary muscles, and form, therefore, an important factor in the diagnosis of myotonia congenita.

Electrical Examination of the Eye.

The electrical examination of this organ has been made use of by various observers, and found to be of considerable assistance in the diagnosis of the diseases affecting it. It is performed in the following manner: A flat sponge-electrode is placed at the back of the neck, on the side corresponding to the eye to be examined. The reason of this is that if the sponge be placed in the median line both eyes are apt to be affected, on account of the diffusion of the current. The active electrode should be placed directly upon the closed lids of the eye to be examined. The ordinary small, round hand-sponges which come with every battery do very well for this purpose. Both eyes should be closed during the examination, and it is much better to have them closed a few minutes before, so that the retina may become entirely free from usual impressions.

Erb recommends that the examination be conducted in a darkened room, which is an excellent idea. The quantitative estimation of optic irritability can never be of much value until the milliampèremeters which physicians have at their command are more satisfactory. Even if the scales of the instruments are correct, they are generally so small that slight variations of the needle, such as fractions of a milliampère, are hard to appreciate. The current necessary to produce the reaction of light in the normal eye is about one milliampère. It is evident, therefore, that the instrument that is used in these experiments should have a scale so large that halves and quarters of a milliampère can be read off with ease and accuracy.

The normal reaction of the eye, the colors, etc., will be found fully set forth in the chapter on electro-physiology. As to the electro-diagnosis of diseases of this organ, there yet remains much to be found out, and it offers a most inviting and fruitful field to the specialist in ophthalmology.

As mentioned above, with a current of one milliampère, or thereabouts, a distinct sensation of light should be perceived, as well as color. The difference between the positive and negative poles ought also to be discernible by the patient. In examinations of the eye, as well as of all

the special senses, great patience and skill are necessary. It is also desirable that the weakest possible currents should be employed, in order to avoid the production of headache. The most important variations from the normal are absence of the perception of color, diminished sensibility to light, and the loss of the ability to distinguish between the poles. These conditions generally indicate the presence of neuritis optica, or atrophy of the optic nerve. It may be mentioned, also, that it is possible to obtain reaction of the iris by means of the faradic current. In order to do this, the pole must be applied directly to the cornea, and, on this account, it can only be done in cases of ether narcosis or unconsciousness from some other cause.

Electrical Examination of the Ear.

The early methods for examining this organ generally required that the external meatus be filled with water or a solution of salt. This was found to be quite objectionable for many reasons, and is now for the most part abandoned. Among the various methods in use, the author would recommend, for the active electrode, the ordinary small, round sponge which comes with all batteries. The indifferent electrode should be a flat sponge, which may be slipped beneath the collar at the back of the neck.

The normal formula of reaction of the auditory nerve may be found fully explained in the chapter on physics. In examining for the pathological changes in the auditory nerve, special skill and great patience are required, since the results obtained are often very misleading. The most frequent variation from the normal is what is known as simple galvanic hyperæsthesia. In this condition the nerve is so sensitive that currents so weak as hardly to stir the needle of the milliampèremeter will produce a distinct sensation of sound. Moreover, the sounds which are produced are of very marked character,—whistling, singing, or ringing,—and they last for a much longer time than ordinary. In spite of this excessive sensibility, the normal formula, as explained in a previous chapter, remains unchanged.

Cases frequently occur, however, where, in addition to the hyperæsthesia, we may have also anomalies in the formula. For example, there may be present a ringing sensation with An. Cl. and An. D. If the current is strengthened, the same ringing may occur with Ca. O. Moreover, these sounds so produced have a distinctly pathological character, which distinguishes them from those brought out by the galvanic current in the normal ear.

All varieties of change from the normal formula may be found in different diseases of the ear, without any hyperæsthesia or increase in the sensibility. The anomalies are generally seen in chronic diseases of long standing. They are supposed to owe their origin to injuries of the skull, or to disturbed nutrition. Another anomaly is known as torpor

of the auditory nerve. Owing to the difficulty of obtaining the reaction, even under normal conditions, the diagnosis of torpor of this nerve should be made with great caution. In such cases the resistance should always be determined, in order to be sure that its increase may not account for the torpor. This anomaly is met with in serious and incurable affections of the auditory apparatus.

The Sense of Taste.

This sense is best examined by means of an instrument invented by Neumann. It consists of a long stem carrying two wires isolated from each other and ending in little balls, which form the two poles of the current. By means of this electrode any part of the tongue or inside of the buccal cavity may be examined and the sensations of taste noted. As yet no practical application has been made of this method to the diagnosis of disease. As to the reaction of the nerves of smell to the electric current, nothing of any moment is yet known.

Examination of Common Sensation.

It must be acknowledged that the electrical examination of sensory nerves is not by any means as important as that of the motor nerves. It is, however, a more accurate, and at the same time more convenient, method than the various others employed for the purpose. Up to the present time we know of but two variations from the normal to be found by this method: hyperæsthesia, or increased sensibility; and anæsthesia, or decreased sensibility. In testing the condition of the sensory nerves, the active electrode is so made as to present a great many points of contact. Erb devised one made of a large number of wires fastened together so that their ends presented a smooth surface. Modifications of this form have since been made, but all with the same end in view,—of obtaining as many points of contact as possible.

The method of finding out the sensibility of the surface of the body is as follows: The electrode just described is connected with the faradic coil and placed upon the portion to be examined. The other, or indifferent, electrode may be placed anywhere. The coils are now brought together until a very slight sensation is felt, and the coil-distance noted. They are now pushed still farther on until a painful sensation is produced, and the coil-distance again noted. From numerous observations averages are obtained for different parts of the body. These averages, once found, enable the observer to detect deviations from the normal. Such deviations occur in various diseases of the brain, spine, and peripheral nerves.

Bernhardt has tested the reaction of cutaneous sensibility, and finds that it varies in different areas or zones of the body. He divides the surface of the body into nine zones, as follow :—

1. Tongue zone (tip of tongue, palate, tip of nose).
2. Face zone (eyelids, gums, red surface of lips, cheek).
3. Forehead zone (forehead, cutaneous surface of lips).
4. Shoulder zone (shoulder).
5. Trunk zone (sternum, nape of neck, spine, arm, forearm, buttock, occiput, front of neck).
6. Thigh zone (sacrum, thigh, dorsum of foot).
7. Hand zone (back of hand, leg, ball of fingers).
8. Patellar zone (patella).
9. Digital zone (tip of toes, palm of hand, sole of foot).

The average minimum coil-distance of sensation and of pain for these various regions is given in the following table :—

Zones.	General Electro-sensibility of the Skin. Average Min. C. D.	Painful Electro-sensibility of the Skin. Average Min. C. D.
1. Tongue zone	166. millimetres.	136.7 millimetres.
2. Face "	150.5 "	130.5 "
3. Forehead "	144.5 "	128. "
4. Shoulder "	137. "	112.5 "
5. Trunk "	128. "	110.8 "
6. Thigh "	122.1 "	99.1 "
7. Hand "	116. "	92.8 "
8. Patellar "	111. "	88. "
9. Digital "	114.5 "	67.8 "

As the difference in the resistance of the skin at various points may cause an error in the result, Erb recommends that this resistance be found in each case by means of the galvanic current. He found that, in some cases, differences in the sensibility at corresponding points on opposite sides of the body could be explained by this difference of the resistance to the current.

The electrical examination of common sensation is of special interest and value in cases of locomotor ataxia. The sensibility of the whole surface of the body will often be found very much decreased. The sensibility to pain is generally affected in proportion to the general sensibility, but in certain cases there will be absolute and complete analgesia, even when the coils are pushed entirely together so as to give the strongest possible current. In unilateral affections, where one side of the body remains comparatively normal, as, for example, in cases of injury, the difference in the farado-cutaneous sensibility on the two sides can often be clearly and beautifully brought out.

Sensation of Internal Organs.

Attempts have been made at various times to investigate the sensibility of the internal organs, but, so far, without very material result. Duchenne investigated the peculiar feeling produced in a muscle by the passage of an electric current through it, but did not arrive at any very important conclusions.

CATAPHORESIS, ANODAL DIFFUSION, ELECTRICAL OSMOSIS, OR VOLTAIC NARCOTISM.

By FREDERICK PETERSON, M.D.,
NEW YORK.

From a medical stand-point we understand by cataphoresis the introduction of medicaments by means of electricity into the body through the skin or mucous membranes. It seems to be a purely physical process, and has nothing to do with electrolysis. As is well known, particles of carbon in the Davy arc-light are carried from the positive to the negative pole.

Physically and not physiologically speaking, it is almost certain that electrical endosmosis is a mechanical and not an electrolytic effect, for two reasons : first, the action will show itself in any single solution whenever a porous partition, such as plaster of Paris, stoneware, etc., is inserted in the path of the current, even when no electrolysis is taking place,—that is, no decomposition ; and, secondly, because the phenomenon may be stated as follows : Whenever a capillary tube containing liquid sustains a difference of potential between its extremities, liquid is transferred through the tube toward the cathode. The fact that the flow is proportionate to the difference of potential with a given current is equivalent to the usual statement that the effect increases with the resistance of the septum, because, the greater the resistance, the greater the difference of pressure that a fixed current will establish between the surfaces. The converse of the proposition also holds good ; that is, whenever liquid is forced through a capillary tube, a difference of potential is set up between its ends. Thus, a flow of liquid through a plug of plaster under hydrostatic pressure will set up a difference of potential opposite to the direction of flow between the bounding surfaces. This phenomenon is commonly called capillary electro-motive force. The cause is not known ; it is some definite mechanical or dynamic action, and Helmholtz has given a working theory, but it will probably be understood only when electricity is understood. This is the view of Kennelly, Lewandowski, and myself.

The following facts explain the character of the process in a clearer and more popular form : If two compartments separated by a membrane are filled with a fluid and in each an electrode is placed, there is a streaming of the fluid through the septum in the direction of the galvanic current,—that is, from the positive to the negative pole,—so that in the

course of time there is an increase of fluid in the negative compartment. This osmosis, as is well known, occurs naturally without the use of electricity between two dissimilar liquids, the direction of the osmotic current being from the lighter to the denser liquid. But if the anode is placed in the denser liquid and the cathode in the lighter, this natural osmotic current is not only overcome, but reversed. Du Bois-Reymond termed this the cataphoric action of the constant current. This streaming movement is analogous to that taking place in the semi-solid sarcous substance of muscle when subjected to the constant current, and observed under the microscope,—a visible flowing of the contents of the muscular fibre from the positive to the negative pole, causing a swelling of the fibre at the negative end. This is called Porret's phenomenon in living muscle. W. Kühne has experimented on this.

Now, it has been found that the skin of animals is permeable to drugs. The degree of absorption varies in different animals, and depends upon the quality of drug employed and the manner of its application to the skin. Thus, the skin of the frog absorbs water or watery solutions rapidly (Guttman), while that of man does not do so at all, because of the fat normally present upon the epidermis and in the pores. Solutions containing alcohol, ether, or chloroform, by removing the fat, render absorption easy (Parisot). All substances which are volatile and corrode the epidermis, like carbolic acid, are readily absorbed (Röhrig). Watery solutions striking the human skin in a finely-disseminated spray may reach the interior of the body, probably by penetrating the interstices of the epidermis (Juhl).

Massage, in connection with cutaneous medicaments, causes easy absorption by forcing the particles into the pores. Wherever the epidermis is removed, as by an abrasion, burn, or blister, the transference of substances through the skin is rapid.

In 1863 Quincke experimented with a minute column of fluid in a fine capillary tube, at either end of which platinum wires were introduced. When the lower end was made the anode and the current turned on, there was a motion in the liquid in the upward direction. Porous membranes, then, may be looked upon somewhat as a large number of capillary tubes in juxtaposition, and through these the substances in solution are driven by the electric current as it flows from the anode to the cathode. Not only the galvanic current may be used for the purpose of introducing drugs, but also the current from the static machine; but no conclusive experiments have as yet been made with static electricity.

A very pretty experiment, devised by Ehrmann, of Vienna, may be used to demonstrate the cataphoretic power of the anode: Take two similar glass vessels, with zinc electrodes at the bottom, and filled with a very weak solution of methyl-blue. Insert the hands, one in each, and cause 10 to 20 milliampères to pass for from five to ten minutes. The hand in the anode vessel will be covered with blue spots.

The cataphoric action of electricity has often been made use of experimentally to introduce drugs into the system through the skin. The anode, moistened with a solution of strychnine, has been applied to the skin of a rabbit, the cathode being placed upon any indifferent spot, and in a few minutes the animal has died from strychnine poisoning (H. Munk). In man, quinine and potassium iodide have been thus introduced and subsequently detected in the urine (Landois and Sterling, "Physiology," p. 489).

Efforts have been made more particularly, however, for the purpose of producing a local anæsthesia by the use of electro-chemical osmosis. As far as I can learn, the first investigator in this direction was Dr. B. W. Richardson, who wrote two articles on "Voltaic Narcotism" in 1859.[1] He began experimenting in October, 1858, by producing a local anæsthesia with a solution of morphine on the anode. Then, with a simple galvanic current and with tincture of aconite on the positive pole, he brought about complete anæsthesia of a rabbit's ear, after trying in vain to do so with the current alone. After this he made the following solution:—

℞	Tinct. aconiti, ...	ʒiij.
	Ext. aconiti alc., ...	℈j.
	Chloroformi, ...	ʒiij.—M.

One-third of this was put on a sponge, which was wrapped around the upper part of the hind-leg of a dog, after shaving it, and attached to the positive pole, the other pole being applied to the ankle. In eleven minutes there was complete anæsthesia to transfixion with pins anywhere between the electrodes. A minute later a subcutaneous section of the tendo Achillis was made without pain. At the end of an hour the limb was amputated about an inch below the knee without a wince until the bone was sawed, when the animal screamed once, but it was not known whether this was from pain or terror. There was no pain in the subsequent manipulations. Twenty minutes later the animal ate heartily and walked about unconcernedly upon three legs. The wound healed by first intention. Subsequently, transferring his experiments to mankind, he painlessly removed a one-inch nævus from the shoulder of a ten-week-old babe, after half an hour's voltaic narcotism with 5 minims each of chloroform and tincture of aconite. Then, in five cases of extraction of teeth, a fine anode wound with cotton soaked in the same solution of chloroform and aconite produced complete anæsthesia in ten minutes. Afterward a new method was used successfully in a case of strangulated hernia in a man; in one of tumor of the shoulder, of the size of an orange, in a woman aged 47 years; and in one of staphyloma of the cornea. Equal parts of chloroform and tincture of aconite were used in all, and the duration of the narcotic process varied from half an hour to an hour.

[1] Med. Times and Gazette, February 12 and June 25, 1859.

It is needless to say that Richardson's articles roused a storm of opposition in the medical press of England and the Continent. The ground taken by his opponents may be illustrated by the conclusions of A. Waller,[1] which are as follow: Insensibility from so-called voltaic narcotism is produced solely by the local absorption of the chloroform-and-aconite mixture. Anæsthesia is produced with equal efficacy by the mere topical application of the narcotic mixture without the electric current. . The procedure is, in itself, painful, and the result is inflammation and disorganization of the skin.

It is to be regretted that Richardson himself subsequently abandoned the position he had taken with regard to voltaic narcotism.[2] The subject slumbered for more than twenty-five years, and has only of late years been revived, or rather re-discovered, for Richardson's articles had, in the meantime, been so completely forgotten that no reference had been made to them anywhere until I called attention to them in my first article in 1889. Wagner[3] re-introduced the matter to the profession in 1886 by a short note on the possibility of cocaine anæsthesia with the galvanic current, but without definite experiment. But Adamkiewicz has written more fully upon this subject of late than any one else. His first article, in 1886, described what is known as his diffusion electrode,[4] with which he professed to introduce chloroform into tissues and produce local anæsthesia. He found chloroform would evaporate too rapidly from the ordinary sponge-electrode, and hence devised this new instrument. It holds three cubic centimetres of fluid in a hollow brass cylinder, the bottom of which is of porous carbon. Over the carbon bottom a piece of moistened linen is stretched to prevent burning when in contact with the skin. This instrument is made the anode, of course, and applied to painful spots in neuralgia with a 3- to 5- or 7-milliampère current. He professed to obtain a gradual anæsthesia with disappearance of pain, and had employed the method with chloroform in rheumatic pains and neuralgias of the intercostal and trigeminal nerves,

This revival of Richardson's discovery was again met by strong opposition and criticism. Paschkis and Wagner[5] maintained that chloroform was almost a complete insulator and did not conduct at all; that, though anæsthesia was produced, it was solely due to contact of the chloroform with the skin, and that the gradual disappearance of the chloroform from the electrode, noticed by Adamkiewicz and ascribed by him to cataphoresis, was nothing but an evaporative phenomenon.

Adamkiewicz replied that, though a poor conductor, chloroform did conduct, and that anæsthesia was produced in four minutes, first to temperature and then to pain; that with a strong current deep slough-

[1] Med. Times and Gazette, March 19 and July 30, 1859. See, also, views of J. Althaus. Wein. Med. Woch., ix, 1859, p. 433.

[2] Med. Times and Gazette, February 3, 1866.

[3] Wiener Med. Presse, 1886, S. 212.

[4] Neurolog. Centralbl., Bd. v, S. 219–497.

[5] *Ibid.*, Bd. v, S. 413.

ing could be produced in a few minutes, which chloroform alone could not induce for hours, and he was able to show cataphoresis with the galvanic current in a rabbit's ear by staining chloroform with gentian violet. Afterward he reported three cases of neuralgia, at the Sixth Congress für innere Medecin,[1] relieved by his method, with a 1- to 7-milliampère constant current, where other means had failed to do any good.

Lumbroso and Matteini[2] have employed chloroform with ordinary electrodes and 10 to 12 milliampères in neuralgia, always with great success in relieving pain; whereas the current alone, without chloroform, produced no result.

Dr. J. L. Corning[3] has reported some experiments of his with cocaine cataphoresis. He tried a 5-per-cent. solution with the anode and produced a slight effect. He then perforated the skin by means of the Baunscheidt needles, and was able to produce anæsthesia with a $2\frac{1}{2}$-per-cent. solution of cocaine on an ordinary sponge-electrode. He reported, however, no cases.

Dr. Reynolds,[4] of Chicago, published, in 1887, an article upon the use of cocaine in 2- to 20-per-cent. solutions with the anode, in his dermatological practice for small cutaneous operations and for the electrolysis of hair-roots. He also used voltaic narcotism in one case of tooth-extraction, as had been done by Richardson just thirty years before.

My own early experience with electric cataphoresis extended over many months of time in 1888, and my experiments numbered much over a hundred, about a fourth of which I reported in detail in 1889. Actuated by the great diversity of opinion among the investigators I have quoted, I began at the foundation, in order to demonstrate to my own satisfaction the actual facts in a scientific manner. My early trials are here reproduced:—

Experiment No. 1. *Uselessness of the Adamkiewicz Electrode.*—Barrett 50-cell chloride-of-silver battery. Placed three cubic centimetres of a 4-per-cent. aqueous solution of Merck's cocaine in the Adamkiewicz electrode (diameter, four centimetres) and made it the anode. Applied this to the skin over first interosseous muscle, between the thumb and index finger of the left hand, an ordinary sponge-covered negative electrode five centimetres in diameter being placed in the palm of the same hand. Both sponge and linen over the two electrodes were first well moistened. The current from eighteen cells was used for three minutes. No change of any kind in sensibility.

Experiment No. 2.—Same details as in No. 1, but current contact for five minutes. No change in sensibility.

[1] Neurolog. Centralbl., Bd. vi, S. 238.
[2] "Sulla cataforesi elettrica," La Riforma medica, July and November, 1886.
[3] New York Med. Jour., November 6, 1886.
[4] Jour. of the Amer. Med. Assoc., August 20, 1887.

Experiment No. 3. *Current Painful.*—Same details as in No. 1, except that twenty cells were used for three minutes, causing severe prickling and burning sensation at once. Very feeble anæsthesia to touch and slight hyperalgesia on pricking, possibly due to the pressure on the terminal sensory filaments by the intense congestion produced by the anode. Sensibility normal three minutes later.

Experiment No. 4.—Same details as in No. 3, but current applied for ten minutes. Exactly the same sensory disturbance as in last experiment.

Experiment No. 5. *Defects in Adamkiewicz's Electrode.*—The Adamkiewicz electrode was replaced by an ordinary sponge-covered metal electrode two centimetres in diameter, soaked in the 4-per-cent. solution of cocaine. Details same as in No. 3. Current applied for six minutes. Could then prick with a needle until bleeding occurred (in a spot one centimetre in diameter, where cocaine had been applied) without its being felt, and there was also complete anæsthesia to touch and temperature. This anæsthesia lasted ten minutes. Investigating into the cause of this remarkable difference in results, I found that the electrode of Adamkiewicz was absurdly faulty in construction. The metal cylinder, with its carbon bottom, was a piece of inexcusable stupidity. As the electric current travels where there is least resistance, it is evident to the merest tyro that the whole current will traverse the metallic part of this electrode, and not a vestige pass through the fluid and carbon disc, when it is applied closely to the skin.[1] The resistance of chloroform amounts to billions of ohms. I consequently abandoned any further use of this instrument for therapeutic purposes; but subsequent experiment with it showed very clearly that its inventor produced local narcosis to a certain extent. The law should not be lost sight of that the amount of electrical osmosis grows with the resistance of the fluid acted upon. Hence the enormous resistance of chloroform adds to its cataphoric power. The electrode of Adamkiewicz doubtless did carry chloroform into the tissues, notwithstanding the criticisms of Wagner and Hoffman; for the bottom, when in use, is covered with moist linen, and no doubt a thin layer of chloroform would get between the circular metallic rim and the skin. Hence both Adamkiewicz and Hoffman are right in some of their statements and wrong in others. My own experiments with chloroform sufficiently attest this. Thus, as the current passed through the metallic rim, it met with an infinitesimal quantity of chloroform and transferred it through the skin, producing some narcotic effect. But evidently Adamkiewicz was very much deceived in his instrument, for he believed the contained liquid would pass through the carbon disc, and actually thought he detected an appreciable diminution in the quantity of liquid held by his instrument.

[1] I see that this has also been quite recently pointed out by J. Hoffman (Neurolog. Centralbl., November 1, 1888).

Experiment No. 6. *No Anæsthesia with Cocaine Alone.*—This experiment was undertaken for the purpose of ascertaining if the electric current really had any effect in hastening anæsthesia. A 4-per-cent. solution of cocaine was applied to the skin of the dorsal surface of my left hand for twelve minutes by holding the open mouth of the bottle containing the solution against it. The skin surface in contact with the solution was one centimetre and a half in diameter. No anæsthesia of any kind was produced.

Experiment No. 7. *None with 10-per-cent. Solution.*—For same purpose as No. 6. Soaked a metal sponge-covered electrode, two centimetres square, in a 10-per-cent. solution of cocaine and applied to skin over first interosseous of my left hand for ten minutes without current. No anæsthesia whatever produced.

Experiment No. 8. *No Anæsthesia with Current Alone.*—Same electrode as in No. 7 to same place. A large sponge-covered wire-netting cathode, some eight by twelve centimetres square, in the palm of same hand. Sixteen cells of a Grenet battery for six minutes without cocaine. No anæsthesia whatever.

Experiment No. 9. *Current and Cocaine Together Cause Marked Anæsthesia.*—Same electrodes and application as in No. 8, but with 10-per-cent. solution of cocaine on the anode. Contact for five minutes with sixteen cells of Grenet battery. Complete anæsthesia to touch, pain, and temperature lasting over an hour in surface in contact with anode. It is known that the anode normally paralyzes the vasomotor nerves, producing congestion and œdema, while cocaine has the opposite effect, contracting the capillaries; but, when applied together, the normal electric effect outbalances that of cocaine, and the part under the anode remains congested. The current itself with this strength is somewhat painful at first at the anode, but as anæsthesia appears the pain gradually diminishes and ultimately disappears.

Experiment No. 10.—Exactly same details in every respect as in No. 9, but applied to the hand of Dr. J. A. Booth instead of my own. Same anæsthesia as on myself. Repeated this the next day on Dr. Booth for seven minutes, with same result. The anæsthesia in these short applications is always limited to the area of the anode.

Experiment No. 11. *No Effect with Cathode.*—Exactly same electrodes and application as in No. 9. Same number of cells, but commutator reversed so that the 10-per-cent. solution of cocaine was on the cathode. Contact of current for five minutes. Result: continual increase of pain at spot under cathode and no anæsthesia whatever,—the very opposite effects produced by the anode.

I had now satisfied myself that a watery solution of cocaine alone, applied to the skin, or upon the cathode with a strong continuous current, and that the current alone without cocaine, could produce no cuta-

neous anæsthesia, but that there was an actual cataphoresis of the cocaine solution and consequent anæsthesia of considerable duration with the anode. I then proceeded to make therapeutic use of this method.

Experiment No. 12. *Successful Use of Cocaine; Cataphoresis in a Case of Supra-orbital Neuralgia.*—Dr. E. C. Seguin kindly placed at my disposal an obstinate and severe case of right supra-orbital neuralgia. L. E., female, aged 40 years. Duration of neuralgia, a year and a half. Everything tried unavailingly. Suffering every few minutes with the usual agonizing pains of the disease. There was slight analgesia over right half of the forehead and right side of the nose, but exquisite hyperæsthesia of the tactile sense in the same areas, so that a slight touch or breath of air was exceedingly painful. There was great tenderness on pressure. The two-centimetre square anode with a 10-per-cent. solution of cocaine was placed in the right supra-orbital region over a painful spot, and the eight-by-twelve-centimetre sponge and wire cathode in the right palm. Nine Grenet cells were used for three minutes, then raised to eleven cells for two minutes longer, which caused prickling, but no pain; and then raised to thirteen cells, which was too painful, and was reduced to twelve cells, and continued for five minutes. The whole application lasted ten minutes without break of current. There was no neuralgic pain during this time and the hyperæsthesia had disappeared. There was the expected anæsthesia. The patient was completely relieved from pain for from four to five hours.

Experiment No. 13.—A second similar application was made the next day in the same case, by Dr. Seguin, at his office, with equally gratifying results.

Experiment No. 14.—Same case and same electrodes as in No. 12. Seven Grenet cells; five milliampères current-strength; 10-per-cent. solution of cocaine; six minutes' application. Equal relief.

Experiment No. 15.—Same case and details. Eleven cells; 10-per-cent. solution of cocaine; six minutes. Equal relief.

Experiment No. 16.—Same case. Application by Dr. Seguin. Ten-per-cent. solution of cocaine; fifteen milliampères current-strength; twenty minutes' contact, moving slowly over different parts of right supra-orbital region. Very great relief for five hours.

Experiment No. 17.—Same case. Sixteen to twenty cells; 10-per-cent. solution of cocaine; five to seven milliampères current strength; nine minutes. Same relief. In this case aconitine pushed to its toxic effects did not relieve pain. The cataphoric application is still in use in this case, and always with the marked results mentioned. Latterly, several applications of the anode with a 20-per-cent. solution of cocaine have been still more distinctly beneficial. On one occasion she had eleven hours of perfect freedom from pain, the longest interval of relief in a year and a half. Whether any actual curative effect will be pro-

duced, it is now too early to determine. The patient herself is so convinced of the efficacy of this method that she will now try nothing else.

Experiment No. 18. *Successful Use of Cocaine Cataphoresis in Another Case of Chronic Supra-orbital Neuralgia.*—This second case was also placed at my disposition by Dr. Seguin. J. F., male, aged 60 years; extreme suffering from right supra-orbital neuralgia for twelve years. Internal administration of aconitine is gradually relieving him, but pains every few moments exceedingly severe. Same electrodes and application as in No. 12. Ten-per-cent. solution of cocaine. Five cells; six minutes. Anæsthesia slight. Pain relieved. Cannot endure so much current as No. 12.

Experiment No. 19.—Same case. Ten-per-cent. solution of cocaine; nine cells of Grenet battery; three milliampères and a half current-strength; six minutes and a quarter. Great relief and considerable anæsthesia.

Experiment No. 20.—Same case. Very little pain for past forty-eight hours since last application. Aconitine probably doing its work. Great tenderness on pressure over supra-orbital nerve. Cocaine as before. Eleven cells, seven minutes. Complete anæsthesia produced. No pain on pressure.

Experiment No. 21.—Same case and condition as in last. Cocaine as before. Fifteen cells; five milliampères; ten minutes. Same result.

Experiment No. 22.—Same as last. Fifteen to eighteen cells for eight minutes. Same result.

Experiment No. 23. *Successful Use of Cocaine Cataphoresis in Inferior Maxillary Neuralgia.*—Tried by Dr. J. A. Booth, and notes kindly furnished me by him. Inferior maxillary branch of left trigeminal. Neuralgia for three weeks. Cathode in right hand. Anode over left mental foramen. Ten-per-cent. solution of cocaine. Both electrodes five centimetres in diameter. Seventeen Leclanché cells; seven milliampères current-strength; five minutes and a half contact. Spoke very soon of relief caused. Slight anæsthesia produced.

Experiment No. 24. *Deep Analgesia with the Cataphoric Use of Aconitine.*—I now performed several experiments upon myself with the same apparatus as before, but substituting an alcoholic solution of aconitine (gr. iv to ℥j) for the cocaine on the anode. Result: In two or three minutes deep-seated analgesia, but tactile hyperæsthesia; a painful burning sensation, the area covered by anode whitened and elevated. The analgesia to pricking and the burning sensation continued for an hour. The pallor disappeared after a quarter of an hour, giving place to redness. There was no excoriation.

Experiment No. 25. *Relief of Dorsal Neuralgic Pains in Locomotor Ataxia by Aconitine Cataphoresis.*—S. B., male; a case of locomotor

ataxia suffering from intense neuralgic pains in the back at mid-dorsal region. Cathode on left side of abdomen. Anode one centimetre in diameter with aconitine, as in No. 24, to region of greatest pain. Fourteen Leclanché cells, five to six milliampères current-strength, four minutes' application. A white elevated disc, larger than the area of anode, was produced, which was completely analgesic and anæsthetic for an hour, but in which there was a burning sensation for an equal length of time. The neuralgic pains were relieved for eight or nine hours. This was tried again a few weeks later with 10 minims of tincture of aconite on the anode, with equal effect.

Experiment No. 26. *Relief in a Case of Double Trigeminal Neuralgia from Cataphoric Use of a Mixture of Cocaine and Aconitine.*—E. B., female, aged 30; excruciating double trigeminal neuralgia of a year's standing, upper two branches. Had tried blisters, electricity, and aconitine internally, and once had morphine habit. No day without pain. Twenty-eight chloride-of-silver cells. Water rheostat. Twenty-per-cent. solution of cocaine on anode one centimetre in diameter to right temple over painful spot for twelve minutes. Cathode six by ten centimetres in right palm. Complete anæsthesia and analgesia and relief in that side. Same for five minutes to left temple with like beneficial result. Then four minutes over main trunk of nerve in front of right ear, with a mixture of equal parts of 20-per-cent. solution of cocaine and the solution of aconitine (gr. iv to ℥j), causing deep anæsthesia to touch and pain. With this last there was slight burning sensation at first, but it subsided in a minute or two. Relief from pain experienced for several hours.

Experiment No. 27. *Cocaine and Aconitine Cataphoresis.*—I now thought it best to try some further experiments upon myself. A six-by-ten centimetre cathode was placed in the left palm, and the one-centimetre anode over the left first interosseous, as before. The anode was well saturated with a mixture of aconitine and cocaine, as in the last experiment. Twelve chloride-of-silver cells; five minutes' application. Result: Complete anæsthesia to touch, pain, and temperature over a space three times the area of the anode, without burning sensation as when aconitine was used alone. There was at first great pallor of skin beneath the anode, which gradually gave way to slight redness in a quarter of an hour. There was slight return of tactile sense in fifteen minutes, and in twenty minutes slight hyperæsthesia to touch, temperature, and pain.

Experiment No. 28. *Trial without Current.*—Same electrode, saturated with same solutions as in No. 27. Held it on the back of my left hand without the galvanic current for eight minutes, frequently rubbing in order to hasten absorption. There was no effect whatever, save redness produced by rubbing; no anæsthesia.

Experiment No. 29. *Very Mild Current for a Longer Period of Time Successful.*—As in some of the experiments here described

unpleasantly strong currents had been used, I tried upon myself the effect of a mild current for a longer period of application than usual. Same electrodes, points of contact, and solutions as in No. 27. Six chloride-of-silver cells; current imperceptible; ten minutes' duration. Marked anæsthesia to pain, touch, and temperature resulted as before.

EXPERIMENT No. 30.—*Use of Chloroform without Current.*—Held a sponge, two centimetres in diameter, well saturated with Squibb's chloroform, against mid-dorsal surface of left hand, frequently rubbing for ten minutes. There was smarting, stinging pain during the whole application, with intense redness; a very slight superficial anæsthesia to touch, but none to pain of pricking. No current used. The trivial anæsthesia disappeared in two minutes, when the part became hyperæsthetic. The redness disappeared in an hour. There was no excoriation of epidermis.

EXPERIMENT No. 31. *Cataphoric Use of Chloroform and Bad Effects.*—Same electrodes and position as in No. 27. Anode saturated with Squibb's chloroform; eighteen chloride-of-silver cells; six minutes' application. Complete anæsthesia to touch and pricking with needle in area of anode, lasting barely four minutes. Application more painful even than that of aconitine. There was no insulation by chloroform. The frequent use of the interrupter showed that a strong current was passing. There was a general redness at first. An hour later there was œdema and pallor, surrounded by an areola of redness. Twelve hours later there were swelling, congestion, redness, dermatitis, and vesication. A week elapsed before complete healing of the injury. There was sloughing of the epidermis and part of the cutis vera.

When I took up the subject of anodal diffusion, in the winter of 1888 and 1889, the bulk of information at my command was limited and uncertain.[1] There was so much controversy on every point, so much diversity of opinion, that even the existence of the cataphoretic power of electricity seemed to be as yet not scientifically proven. I therefore made some hundred experiments upon myself and patients, the most important of which have already been described above.

The results of these experiments were summed up as follows: The current alone does not produce anæsthesia at either pole, although the anode has a transitory soothing effect over painful foci. A watery solution of cocaine applied to the skin is not absorbed, does not produce anæsthesia, except, perhaps, after an indefinitely long period. The same is true of chloroform and of an alcoholic solution of aconitine. A

[1] The following are the titles of my original papers from which chiefly the materials for this chapter have been drawn: "Electric Cataphoresis as a Therapeutic Measure," N. Y. Medical Journal, April, 27, 1889; "Note on a New System of Exact Dosage in the Cataphoretic Use of Drugs," N. Y. Medical Journal, November 15, 1890; "Farther Studies of the Therapeutics of Anodal Diffusion," N. Y. Medical Record, January 31, 1891; "The Introduction of Drugs into the Human Body by Electricity," Phila. Times and Register, March 21, 1891.

watery solution of cocaine is diffused through the skin and subcutaneous tissues by the anode, but not by the cathode. This is true of chloroform, aconitine, strychnine, potassium iodide, corrosive sublimate, tincture of iodine, and other medicaments. The anæsthesia produced by a 10- to 20-per-cent. solution of cocaine on the anode is sufficient for small operations and affords distinct relief for from four to eleven hours in cases of severe neuralgias in superficial nerves, and without constitutional effects. The Adamkiewicz electrode is absolutely worthless, since it is so stupidly constructed that the current does not pass through the fluid contained within it, but through its circular metallic rim. Chloroform, recommended by Adamkiewicz, and by Lumbroso and Matteini, should only be used for cataphoretic purposes when, in addition to producing a local anæsthesia, it is desired to counter-irritate, for it causes a disagreeable dermatitis of a week's duration, as I have had reason to learn by experiment upon myself. It does induce a deep analgesia beneath the anode, but it also vesicates.

Up to February, 1889, I had employed anodal diffusion of solutions of cocaine and aconitine, separately or mingled, in two severe cases of chronic supra-orbital neuralgia, selected for me as crucial tests by Dr. Seguin; in one case of double trigeminal neuralgia; in one case of inferior maxillary neuralgia; in one case of locomotor ataxia for the relief of dorsal neuralgic pains. The success of the measure in all of these cases was undisputed. It gave hours of relief from excruciating pain, and without constitutional effects of any kind. Nothing was claimed for it as a curative procedure, but it certainly proved to be a more than efficient substitute in these cases for morphine, which, as we too well know, is so prone to exact for its hours of solace life-times of wreck and ruin. After the publication of my earlier paper, with the results of experiment and of therapeutic application, other articles began to appear which showed a growing recognition of the value of the method.

Dr. Cagney,[1] of London, reported his experience in the use of cataphoresis before the Harveian Society, November 7, 1889. He employed iodine and a saturated solution of potassium iodide with the anode for labyrinthine deafness, lead palsy, small tumors of the skin and mucous membranes; for syphilitic and other throat affections; for chronic pharyngitis; for nodes and gummata, tubercular ulcers, mucous patches, and papular syphilides; for indolent ulcers, lupus, acute and strumous glands. In the discussion upon Dr. Cagney's paper, Mr. Juler stated that he had found the method useful in tobacco amblyopia.

In the same month Drs. Gärtner and Ehrmann[2] made a communication to the Imperial-Royal Society of Physicians of Vienna, in reference to the cataphoretic use of corrosive sublimate. Dr. Gärtner's electric bath-tub was employed, from four to six grammes of mercuric

[1] British Medical Journal, November 16, 1889.
[2] Wiener med. Blätter, November 28, 1889.

bichloride being dissolved in the water of the bath. A current-strength of one hundred milliampères was passed through the person experimented upon for fifteen or twenty minutes, and subsequently mercury was found in the urine in as large a quantity as 1.3 milligrammes. There were traces of the metal in the urine for from four to six days after the bath.

Some time ago Boccolari and Manzieri[1] announced their intention to study the effects of electric cataphoresis in connection with mineral baths, but I have been able to find no published results of their studies in this direction. They have published, however, their use of anodal diffusion of drugs in parasitic affections of hair-roots.

Woodbury[2] described, in May, 1890, his successful employment of the anode with a solution of iodide of lithium in a case with a syphilitic cutaneous neoplasm. Shoemaker[3] has also written upon the uses of cataphoresis in certain skin diseases. Dr. A. Barth[4] describes cocaine cataphoresis as employed by him in a number of operations upon the tympanum and external auditory meatus, finding a 10-per-cent. solution on cotton connected with the anode very successful.

At the International Congress held at Berlin, in August, 1890, Dr. Bayles, of Orange, N. J., read a communication from Mr. Edison, the inventor, upon the medical employment of cataphoresis. I am indebted to my friend, Mr. A. E. Kennelly, chief electrician of the Edison laboratory, for the following brief synopsis of Mr. Edison's experiments :—

"The first trials were purely physical. With a current of twenty milliampères, lithium chloride was forced through a septum of animal membrane by electrical endosmosis. The second series of trials was upon the person of a healthy young laborer, who dipped one hand in a solution of common salt, and the other in a 5-per-cent. solution of lithium chloride in water, for two hours daily for ten days. His urine, examined before the test, showed no more than mere traces of lithium. His urine, collected during that period, exhibited distinct presence of lithium. Five milliampères. The third trial was upon the person of an old man suffering from acute and chronic uric-acid concretions. He was in an advanced stage of the ailment, and most of his joints were affected; the joints between the phalanges were almost obliterated. He immersed one hand in lithium-chloride solution, the other in common-salt solution, while a current from the 120-volt electric-light circuit was employed through resistance to pass through his body. Measurements of the hand in the lithium-chloride solution showed, after some twenty-five hours of total application, a distinct reduction of bulk. There was also considerable relief from pain, and the general condition of the patient was

[1] Internat. klin. Rundschau, September 2, 1888.
[2] Philadelphia Med. News, June 21, 1890.
[3] Sajous's Annual, 1890.
[4] New York Archives of Otology, April–July, 1890, New York, pp. 100, 101.

ameliorated. The current-strength in his case was 20 milliampères (four times more than the previous healthy subject could stand with convenience)."

The earlier criticisms of medical men, that there was no such thing as the anodal diffusion of drugs, must, in the face of such accumulating evidence, be entirely silenced. It is only a few years ago since, in the discussion of my first paper, some who took part manifested entire incredulity. The far more vital criticism, however, that accuracy of dosage was impossible by this method of medication, was not answered until after further experiment and some thought upon the subject. I published in the *New York Medical Journal*, November 15, 1890, a "Note on a New System of Exact Dosage in the Cataphoretic Use of Drugs." The great drawback, until that time, had been the difficulty of accurately regulating the amount of drug introduced. For this purpose rather complicated electrodes had up to that time been required, and even these had been unsatisfactory. The hollow electrode of Munk with clay bottom, of Adamkiewicz with carbon bottom, and of myself with a membranous bottom, each had failed to determine properly the quantity of the medicament employed. But this is now no longer a valid argument against anodal diffusion, since, by the means I have of late employed, exact dosage is simplicity itself. It is only essential to possess a flat metal electrode, preferably but not necessarily of platinum (platinum is now almost as costly as gold) or tin. A nickel-plated surface will answer. Walling uses a carbon surface, which is probably the best form of all for a cataphoric electrode, although its porosity is a disadvantage; but this may be overcome by impregnating with hot paraffin. This may be made of any size, round or square, convex or concave. A piece of tissue- or filtering- paper or linen is cut to fit over the metal surface. Upon it is placed, drop by drop, the solution of any drug to be used, and the electrode is then applied to the skin. There is then a thin capillary layer of the medicament in the paper disc, between the electrode and the skin, and the quantity of the drug is known. The electrode made for me by Messrs. Waite & Bartlett, of this city, is round, flat, two or three centimetres in diameter, and is provided with a narrow soft-rubber rim at its edge, which, by its close approximation to the skin, prevents any loss of the solution by evaporation. In order to have drugs ready for use at any time, discs of paper to fit the electrode may be charged with aqueous or alcoholic solutions, and then allowed to dry, a drop or two of menstruum being added when they are to be used.

The current is allowed to flow if desired until the medicated disc becomes perfectly dry. In this way we may drive in one or more drops of chloroform, methyl chloride, ether, 10- to 20-per-cent. solutions of cocaine, a 1-per-cent. solution of helleborine, solutions of iodide of potassium, corrosive sublimate, aconitine,—in fact, any drug we wish to employ

in this manner, and at the same time we know exactly how much we are using. To further simplify the method, I have had medicated cataphoretic discs prepared by a pharmacist for use at any time, for the paper discs may be charged with any amount of a watery solution, and, the water being allowed to evaporate, they may be kept on hand indefinitely. It is only necessary to add two or three drops of water to the disc in administering the drug by electricity.

Mr. Otto Boeddiker, the apothecary, of 954 Sixth Avenue, New York, has made for me, and is prepared to supply any one with, the following cataphoretic discs: Discs of menthol, 2 grains; of helleborine, $\frac{1}{25}$ grain; of strychnine nitrate, $\frac{1}{32}$ grain; of iodol, 2 grains; of corrosive sublimate, $\frac{1}{8}$ grain; of cocaine hydrochlorate, $\frac{2}{5}$ grain; of aconitine, $\frac{1}{64}$ grain; of potassium iodide, 4 grains; of mercury succinimide, $\frac{1}{4}$ grain; of lithium chloride, 4 grains.

Dr. Morton has improved upon my paper discs by employing a soluble gelatinous disc impregnated with the drug.[1] It is sometimes useful to prepare the skin a little before treatment, by rubbing with ether, to dissolve out the oil-globules. The anode being applied with the drug, the cathode may be placed anywhere upon the surface of the body, and a current of any endurable strength turned on. The stronger the current, the speedier the effect.

Besides the use of these simple electrodes, it is often desirable to make more extensive applications over wider areas. If, for instance, it were wished to diffuse a solution of lithium about a large joint like the knee, a sufficiently large strip of zinc is covered with sponge or cloth saturated with the solution, tied around the extremity, to be then connected with the anodal rheophore. For diffusion through the whole body a bath-tub is used, one either constructed for the purpose or any ordinary bath-tub. The common bath-tub of our houses is readily converted into an anode by placing a large sheet of zinc on the bottom, and connecting it with an insulated copper wire. The sheet of zinc is then covered over with a board to prevent its contact with the body. When the patient is immersed in the bath, he merely keeps one arm out to grasp the cathode, and the circuit is made.

These are, in brief, the means by which drugs are introduced into the body, and it is clear that any soluble agent may be employed in some one of the ways described. In applying electricity for cataphoretic purposes, it does not matter what kind of cell is employed, but a rheostat and galvanometer are useful if not actually necessary. As regards the current-strength to be employed, one must be guided by the patient's feelings. Anywhere from 5 to 20 milliampères may be used for from five to fifteen minutes. The stronger the current, the shorter the duration of the *séance*. If one has no galvanometer, he may use ten to

[1] N. Y. Medical Journal, 1891.

thirty or more cells of any battery,—Grenet, Leelanché, or chloride of silver.

The *therapeutic indications* for the application of this method of treatment may be thus summarized:—

I was led myself into making a study of electric cataphoresis by my own work in a neurological line, and my first experiments were conducted with a view to relieving pain. I received the suggestion after vainly endeavoring to combat severe supra-orbital neuralgias in several patients. All known appliances and agents of the healing art had been ineffectual,—blistering, electricity, aconitine, and the progressive series of narcotics and anodynes, which generally terminate with the morphine habit. One of the patients had suffered from morphine inebriety for a year, but had recovered from that with her supra-orbital anguish unassuaged, as reported above. I found that 10- to 20-per cent. solutions of cocaine on the anode gave absolute relief in these cases for from four to ten or eleven hours, and without constitutional effects of any kind. A deep analgesia was produced in the area covered by the anode. No doubt constitutional effects would ultimately result by indefinite continuance of the application.

Since that time I have made it a point always to use the cocaine solution in any sort of superficial pain in which I think the anode to be of advantage. The method does not mitigate neuralgic pains which owe their origin to lesions far back of the point to which the electrode is applied, as in disease of the Gasserian ganglion, or the idiopathic neuralgias of central origin; and it is here that cocaine cataphoresis has an actual diagnostic significance.

In the discussion which followed the reading of my first paper upon this subject, Dr. Starr called attention to the possible usefulness of cocaine cataphoresis in diagnosis. Thus, if a pain were complained of, for instance, in some part of the trigeminus, it should disappear under this treatment. If it did not, the lesion could be localized farther back, or it might lead to the conclusion that it was hysterical pain. I had myself an interesting example of its usefulness for this purpose some time ago. I was called in consultation to see a lady who had been suffering for months with a rather superficial but excruciating pain in the knee, following slight trauma. The knee was swollen from blistering, the limb was rigid, the patient sleepless from pain, and anxious to have the leg amputated. The spot upon which I placed the anode with cocaine was so hyperæsthetic that the slightest touch made her wince with pain. Her eyes being closed, I stuck a pin in the part after a few minutes, which she did not notice. When she opened her eyes, the electrode having been removed, I touched the anæsthetic part with my finger, and she winced with pain, the same as before. Although the limb was, I believe, subsequently amputated, my diagnosis of a hysterical knee-joint was amply corroborated by microscopical examination. It

had, also, some sort of corroboration in a case of intense supra-orbital neuralgia which I saw on one occasion with Dr. Starr. A 20-per-cent. solution of cocaine used with a strong current for a considerable period of time did not diminish the paroxysms of pain in the least. A few days afterward neurectomy was performed, and this also had no effect upon the neuralgia, which showed the central character of the lesion.

To Produce Local Anæsthesia for Neuralgias, Superficial Pains, and Cutaneous Operations.—With an additional experience of several years in the frequent treatment of neuralgias of superficial nerves with 10- to 20-per-cent. solution of cocaine on the anode, I can only reiterate my conviction that it is the best means we have for relief of such conditions. Cocaine employed in this way does not *cure* neuralgias of peripheral origin. All that is claimed for it is that it gives relief without producing constitutional effects, and is, therefore, superior to any narcotic given internally, and to any other local application. I have had no experience of the method in surgery, but I quote the following from a letter received from Dr. R. H. M. Dawbarn, June 10, 1889, which will merely serve as an instance of the successful employment of voltaic narcotism in a small operation :—

"I have recently, since reading your article, tried this method upon a child's hand requiring suture of a severed tendon. The injury was an old one, and there was no wound before I made my incision. The anæsthesia from 10-per-cent. cocaine upon the anode, continued with my chloride-of-silver battery (twelve cells) for ten minutes, was very satisfactory."

I have experimented with other local anæsthetics. Aconitine produces a deep analgesia, but it is accompanied with severe smarting around the edges of the anæsthetized area. A combination of cocaine with the aconitine prevents this hyperæsthesia. I was led by a note on helleborine [1] in a medical journal to make use of this alkaloid as a local anæsthetic. Three or four drops of a 1-per-cent. solution of helleborine on the anode have brought about much more gratifying results than cocaine, a deeper and more lasting anæsthesia, and I have never noted constitutional effects. The latter need not be feared, now that dosage has become accurate. At the same time I should advise caution in the employment of so powerful an alkaloid.

Both ouabain and strophanthin[2] (Arnaud's, not Merck's) are strong local anæsthetics, and may be used with the anode in doses of $\frac{1}{250}$ grain or more. One or two drops of chloroform on a tissue-paper disc, placed upon the anode, will bring about a deep analgesia in a very short time, but will be followed later by vesication. When it is desirable to first anæsthetize and then counter-irritate, chloroform cata-

[1] Venturini and Gasparini, British Medical Journal, August 4, 1888.

[2] Fortschritte der Medicin, February 1, 1890.

phoresis may be advisable, and will prove useful in some neuralgias. A mild solution of carbolic acid may also be employed as a local anæsthetic and analgesic.

For the Relief of Local Muscular Spasm in Superficial Muscles. —While my experience with the method has been chiefly in neuralgias of superficial nerves, I have not failed to give it a trial in other conditions where it seemed to be expedient. I have used cocaine and helleborine with the anode in two cases of tic convulsif, placing the electrode over the trunk of the facial or one of its branches. Whatever may be the explanation of its effect, these cases certainly showed very great improvement and a remarkable diminution of the spasm after each application, such as was not obtained from the employment of the electric current alone.

In a case of blepharospasm, cocaine cataphoresis practiced near the outer angle of the eye produced a very marked change in the extent and frequency of the movement. I have no doubt, however, that the results would be better still if we had some drug to use with the anode which would act upon motor nerves in the same way as the local anæsthetics act upon sensory nerves,—if, in other words, we had some trustworthy local paralytic. Atropine and curarine do not seem to answer the purpose.

Effects of Cataphoresis upon Nutrition in Ordinary Applications of the Galvanic Current.—There can be no doubt that the effects of the galvanic current upon nutrition are in part due to the cataphoretic transfer of molecules of protoplasm and liquid from one cell to another, or from a cell to a capillary vessel in the path of the anodal stream; and since the diffusion takes place more readily and more quickly in direct proportion to the current-strength, it behooves us to employ as many milliampères as feasible in our galvanization of the atrophied and paralyzed extremities of poliomyelitis, chronic neuritis, and peripheral-nerve trauma.

Moreover, there would seem to be a possible advantage in the use of nutritive emollients in conjunction with the labile application of the anode to the atrophied member, just as they have been combined from time immemorial in the exercise of the aliptic art (massage).[1]

For Electro-Cataphoretic Baths for General Purposes.—There would seem to be considerable usefulness in the method as applied to mineral baths. Although Gärtner has been at great pains to invent a particular kind of bath-tub with two compartments for electrical purposes, it is not essential to have any such arrangement. By making an ordinary bath the anode, the hands may close the circuit by grasping a cathode suspended just above the bath. Thus almost the whole surface of the body may be subjected to the anodal diffusion of the therapeutic agent dissolved in the bath.

[1] "The Aliptic Art," by Frederick Peterson, M.D., Phila. Medical News, August 11, 1883.

Outside of tonic, stimulating, and alterative, such as are found in health resorts, cataphoretic baths of iodide of potash might prove useful in cases of lead poisoning, etc.

For Topical Medication in Various Local Lesions, such as Tumors, Rheumatic, Gouty, and other Swellings, Various Skin Diseases, Syphilides, etc.—For such cutaneous disorders as are commonly treated by painting with iodine, the use of some of the iodine preparations, such as potassium, sodium, or lithium iodide, iodol, or diluted tincture of iodine upon the anode is indicated.

For rheumatic and gouty swellings, solutions of the chloride, benzoate, or citrate of lithium (all very soluble salts) should be employed with the anode. Dr. Imbert de la Touche has written a very interesting pamphlet lately, entitled "Traitement de la Goutte et du Rheumatisme par l'Électricité," read before the French Association for the Advancement of Science, in September, 1891, in which he describes the successful treatment of such cases by the cataphoretic application of iodide of lithium, and of a solution of bryony (bryone). Among mercurial remedies the imido-succinate and bichloride of mercury are well adapted for cataphoretic purposes. The rhinologist and laryngologist will find the method particularly adapted to the treatment of many difficulties of the upper air-passages, which may require the application of anæsthetics, astringents, or antiseptics.

As a last word, let me say that, while the constant current has proved so very useful to the medical profession for diagnosis, for stimulating nerve and muscle, for electrical endoscopy, and for cauterization, we must not neglect its cataphoretic property, by which remedial agents are diffused through the tissues and fluids of the body to improve nutrition, to produce anæsthesia, to relieve pain, to destroy germs, to modify morbid processes, and to make soluble chemical combinations with deleterious substances which quite frequently collect in the organism.

In view of all the facts which I have adduced in this chapter, there can be no doubt that the anodal diffusion of drugs is destined to far wider application than it has as yet enjoyed, and that the general practitioner and the specialist alike will find the procedure increasingly useful as a practical therapeutic measure. As I have elsewhere[1] written, it opens a way not otherwise attainable for influencing tissue metabolism and for changing morbid nutritive processes, by sending the drugs into direct and immediate contact with diseased parts, through a force which in itself must greatly enhance their active medicinal properties.

In gynæcology cataphoresis has found many friends, and is giving cheering results. In the ordinary inflammatory conditions the general practitioner will find in it a safe and sure remedy. Every day adds to the literature of the subject, which is valuable, because original.

[1] New York Medical Journal, December 28, 1889.

LITERATURE.

Besides those already referred to in the text, there are the following articles which may be consulted: Lewandowski: Article "Kataphorese," in the Therapeut. Lexikon of Dr. A. Bum. Morton: "Note on a New Method of Cataphoresis (Anæmic Cataphoresis)," N. Y. Med. Journ., p. 473, 1891. Ehrmann: Wiener med. Wochenschr., February 1, 1891. Harries: Med. Press and Circular, December 11, 1889. W. H. Walling: Medical World (Phila.), November, 1891. B. W. Richardson: Asclepiad, 1891. "Proceedings of Am. Electro-therapeutic Association," 1892, published in the Journal of Am. Med. Asso., and containing discussion on cataphoresis by Drs. Peterson, Morton, Goelet, and others, and by Messrs. Kennelly and Houston, electricians.

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